WATER QUALITY PREDICTIONS FOR PROPOSED MILK RIVER RESERVOIR

by

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1.0 INTRODUCTION

Water quality of the Milk River Basin has been described by Noton (1980), Block (1984) and A.A. Aquatic Research (1986). It is a hard water, somewhat alkaline and warm prairie river. Water quality impacts are entirely non-point source, centering on cereal crop production, livestock grazing and feedlot activity. Suspended solid concentrations tend to be high, especially in the eastern end of the basin, and elevated winter salinity levels are probably effected by groundwater inflow. Peak flows occur in spring and summer, and on average are 14 times the winter low flow (Planning Division, 1980). The magnitude of spring high flows varies greatly between years. Summer flows are regulated by diversion from the St. Mary River via the North Milk channel.

Existing water quality in the Milk River is generally suitable for most water uses (A.A. Aquatic Research 1986), however, some parameters occasionally exceed published guidelines:

- pH levels and some metal concentrations occasionally exceed guidelines for public water supply, but this is not translated into a major use limitation.

- aquatic life in the lower reaches is potentially limited by low winter oxygen and high summer turbidity and temperature. Aquatic life criteria for some metals, nutrients and phenols are also exceeded at certain times.

- agricultural water uses may be affected, but not limited by total dissolved solids, molybdenum and coliforms

- in the lower reaches recreational activity is seasonally affected by turbidity and fecal coliforms

In order to satisfy future consumptive water demands in the Milk River basin additional storage must be considered. The PFRA has reviewed potential reservoir storage locations and recommended Site 2 be considered. This site is just below the north and south forks of the Milk river (Figure 1). Initial social and environmental considerations have been reviewed by Planning Division, Alberta Environment (1980). In 1985 the decision was made to pursue a project at Milk River Site 2 by launching further feasibility studies and by exploring a possible federal-provincial agreement to construct a dam.

This report documents an initial evaluation of the possible water quality implications of regulating the Milk River at Site 2. It predicts probable average and extreme water quality conditions for the proposed reservoir, and alterations to the existing water quality of the Milk River below the dam. Specific objectives were to:

1. Assess and predict in-reservoir and reservoir outflow concentrations likely to exist under operating conditions for:
    - Total dissolved solids and major ions
    - Phosphorus
    - Oxygen
    - Ammonia
    - Other parameters which may present problems

2. Prepare these projections for average and for extreme conditions, and describe the probable frequency of occurrence of the latter.

3. If any parameters are considered to pose a potential problem, assess the distance downstream any such problems are likely to extend. Identify potential mitigative techniques for such problems.

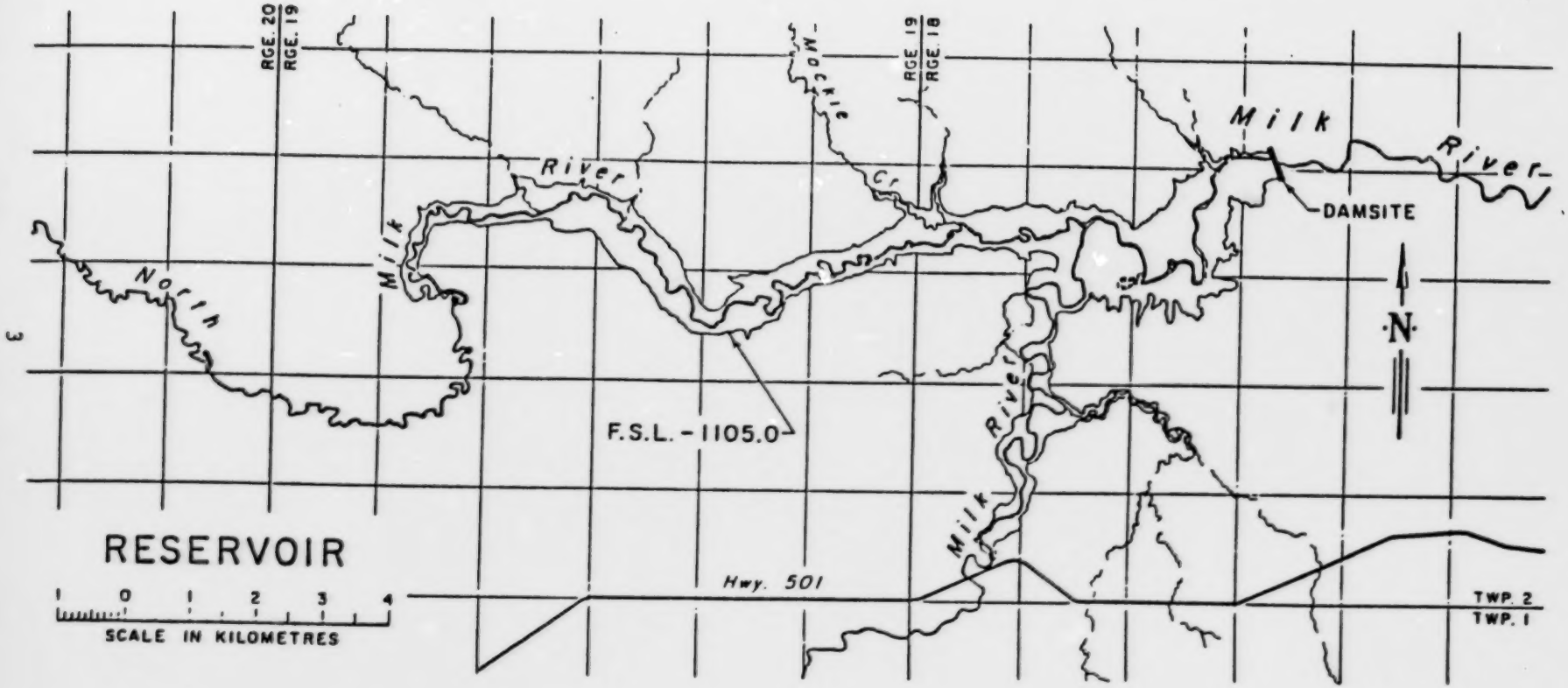


Figure 1. Proposed Milk River reservoir, site 2 location.

4. Evaluate the confidence that can be placed in the predictions and identify significant data gaps or other deficiencies.

The terms of reference were met by applying the Water Quality Planning Model (WQPM) to predict reservoir and downstream quality for most parameters. Alternative methods other than simulation modelling were used to predict:

- reservoir oxygen conditions
- aquatic plant and algal communities downstream of the reservoir
- trophic upsurge
- trace metals and bacteria.

2.0 METHODS

The Major ions and nutrients were simulated with a water quality model previously developed for Planning Division, Alberta Environment (Nanuk, 1986). The Water Quality Planning Model (WQPM) is a stream and reservoir model suitable for predicting steady state river conditions, and seasonal or average annual reservoir quality.

The river system is defined by reaches, each of which is further sub-divided into computational elements. Any element can include one point source input (i.e. effluent) or one withdrawal. In addition, diffuse source inflows to a reach can be defined and the model automatically distributes the flow across all reach elements. All inflows and headwaters must be defined for both quantity and quality (up to 10 parameters). The model maintains a flow balance down the system but does not simulate hydraulic conditions, i.e. depth, velocity, time of travel. It is applicable for well mixed systems and uses advection as the only transport mechanism. Lateral and longitudinal dispersion are excluded and as such it is not appropriate for mixing studies or simulation of events, i.e. short term runoff or batch discharges. Instream processes are simulated by first order decay which may be varied by reach. Winter oxygen can be simulated assuming complete ice cover (therefore zero re-aeration), and the oxygen demand is a simple decay against distance. The stream model is suitable for predicting daily, weekly or monthly average conditions. It can be run in series, i.e. month to month, however the simulated results for one month are not used as input to the next.

The reservoir model assumes complete mixing of inflows and is best run on a monthly timestep, with the end result being a seasonal or average annual value. It can be run with prescribed outflows, or they can be computed in accordance with a storage volume/discharge curve. Evaporation is accounted for. In addition to mass balance of water quality constituents, aerial deposition, sediment retention or release and time decay can be simulated for any parameter. Winter oxygen depletion is simulated according to a defined daily areal oxygen depletion rate.

In order to project a range of conditions over a number of years WQPM was set up to simulate average monthly conditions for a complete ten year interval (1970-1979). This is a medium to high flow interval and the reservoir would remain near full capacity much of the time. Low flows occurred during the 1940's, however, pertinent inflow and calibration water quality data are not available for that interval.

The general model schematics for calibration and production runs are presented in figures 2 and 3, respectively. The channel flows and reservoir elevations were generally defined by runs made with the Water Resources Management Model (WRMM) (Allan Wright, Alberta Environment, pers. comm.). The bracketed numbers on each schematic correspond to WRMM channel declarations. Pertinent items of note for each run are as follows:

Calibration Run

- diffuse source inflow upstream of the reservoir (GSITE2) was apportioned to WQPM reaches 1 and 2 at a 0.3 to 0.7 ratio,

- total river evaporative loss (A31EVP) was divided amongst all reaches according to river distance,

- existing consumptive demands were derived from Planning Services Branch (1986).

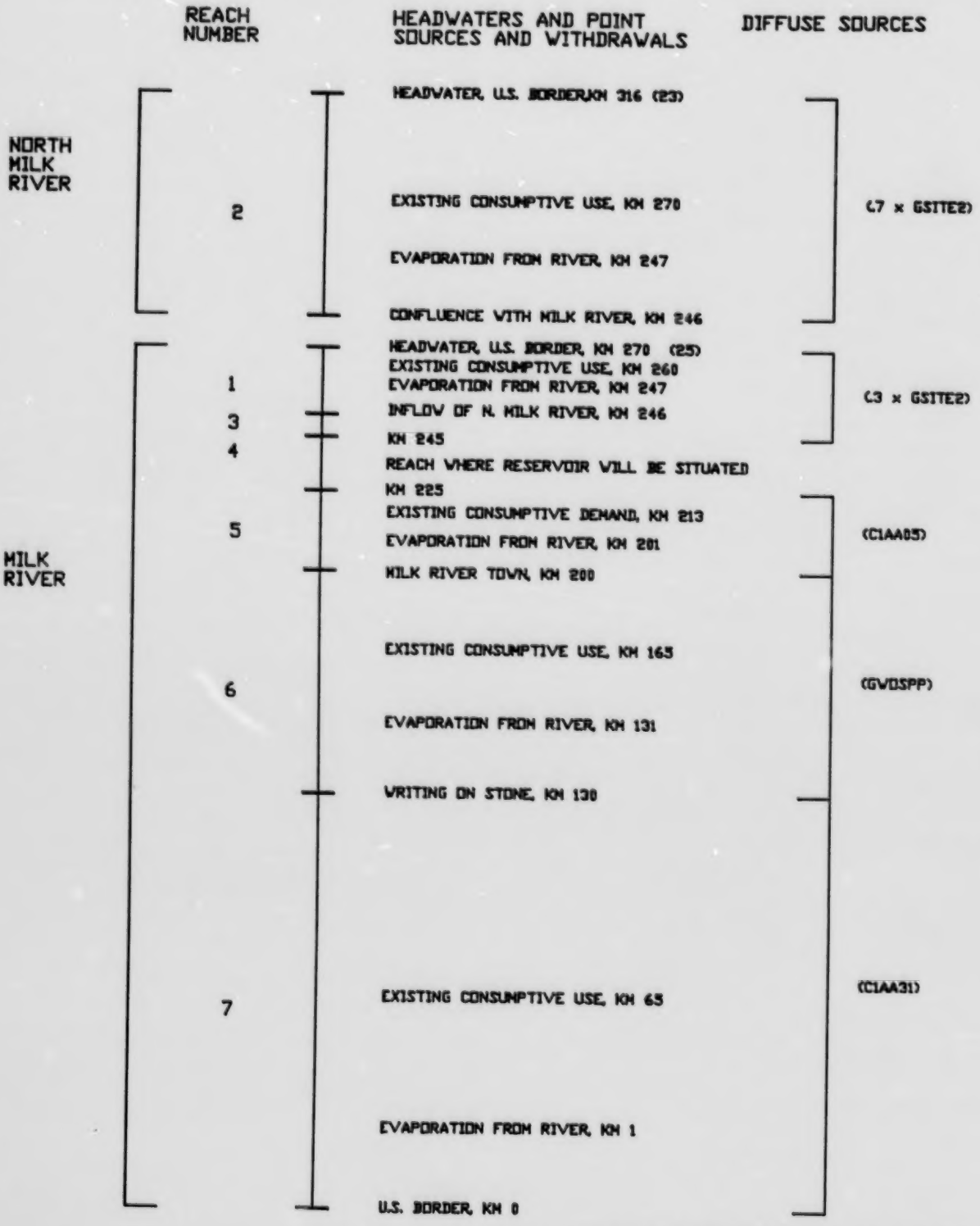
Production Runs

- diffuse source inflow (GSITE2) was entered as per the calibration run.

- consumptive demands were made identical to those defined in the WRMM simulations.

- the total channel loss (A31EVP) was taken from reach 3.

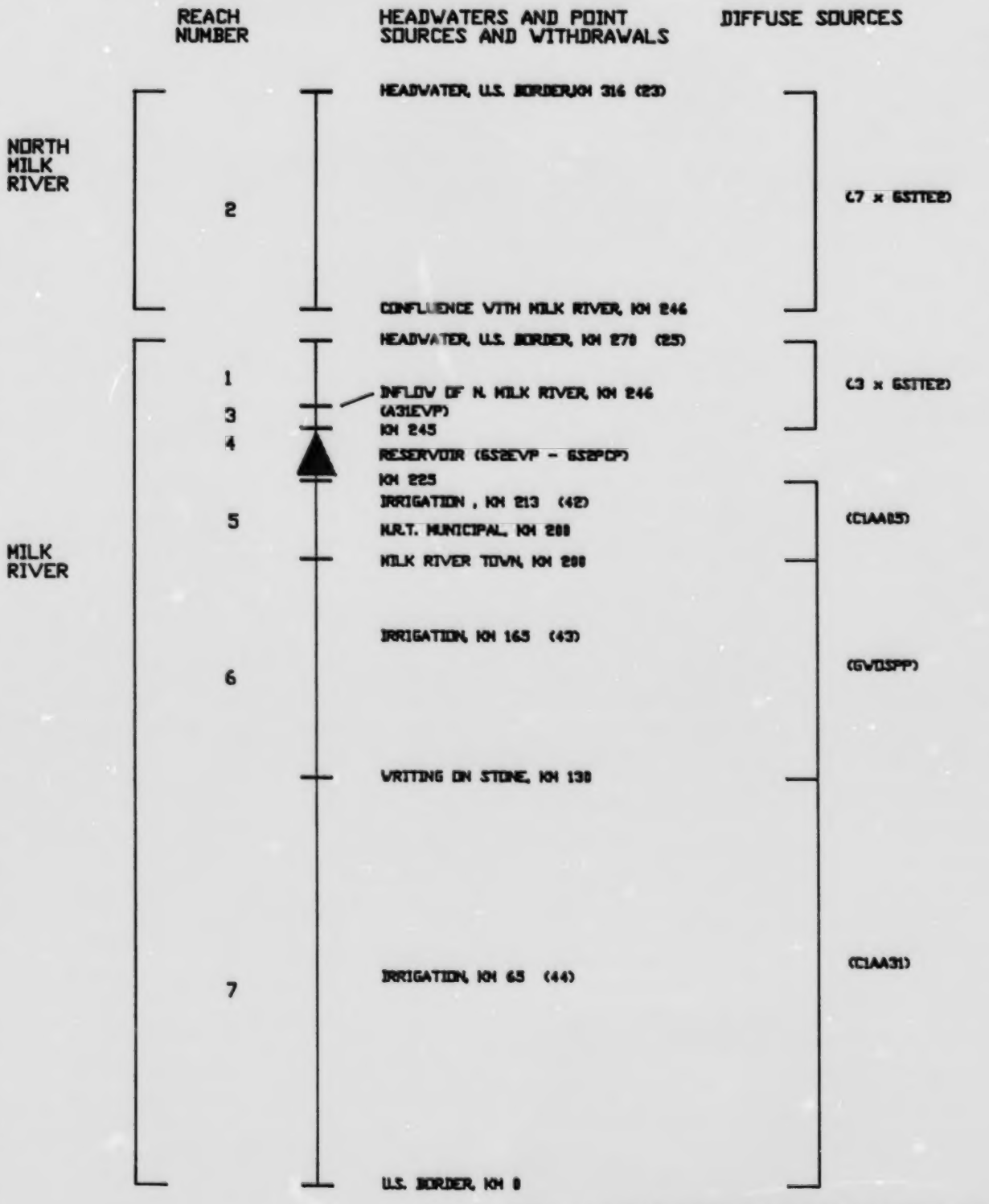
WQPM SCHEMATIC - CALIBRATION RUN



NOTE - VALUES IN BRACKETS REFER TO THE VRMN FLOWS
- 'EXISTING CONSUMPTIVE USE' VALUES ARE TAKEN FROM THE A.E. REPORT 'MILK RIVER BASIN STUDY, CONSUMPTIVE USE OF WATER', OCT. '86

Figure 2.

WQPM SCHEMATIC - PRODUCTION RUN



NOTE - VALUES IN BRACKETS REFER TO THE VRNN FLOWS

Figure 3.

- the reservoir area - capacity curve, evaporative loss and precipitation were identical to those defined in WRMM.

Headwater inflow quality for the Milk and North Milk rivers was set to the 10 year monthly average (1970 - 1979) as defined by Environment Canada's transboundary monitoring data. Diffuse source inflow quality (Table 1) was initially estimated from a synthesis of all available water quality data for tributary streams in the basin, and groundwater quality as defined by Drainage Branch, Alberta Agriculture (J. Hendry, pers. comm.). The final diffuse source inflow quality was set during calibration.

Observed data for the calibration were available at the town of Milk River and the Milk River at eastern crossing. The eastern crossing data were synthesized from Environment Canada's ongoing monitoring program (1970-1979). All available data, federal and provincial, was combined to create the observed dataset at the town of Milk River, including 1986 data collected by Water Quality Control Branch, Alberta Environment.

Table 1. Diffuse source inflow quality as defined from observed surface runoff and groundwater quality plus calibration to observed river data. Units are mg/l except conductivity (usie/cm).

	NFR	CONDUCTIVITY	Ca	Mg	Na	SO_4	NO_3	NH_4	TP
January	100	1200	60	55	189	403	0.01	0.01	0.25
Feburary	100	1200	60	55	189	300	0.01	0.01	0.25
March	300	700	40	20	95	100	0.10	0.10	0.20
April	2000	700	40	20	75	100	0.08	0.07	0.25
May	2000	700	45	20	55	100	0.04	0.05	1.00
June	1750	700	60	20	45	100	0.04	0.06	2.20
July	1250	700	60	20	45	100	0.03	0.01	1.50
August	1000	700	60	20	45	100	0.03	0.01	1.30
September	220	700	60	20	45	150	0.03	0.01	0.35
October	125	700	60	20	100	403	0.01	0.01	0.10
November	30	1200	60	55	189	403	0.01	0.01	0.20
December	30	1200	60	55	189	403	.03	0.01	0.10

3.0 RESULTS & DISCUSSION

3.1 RESERVOIR LEVELS & DOWNSTREAM RIVER FLOWS

The general characteristics for the proposed reservoir are presented in Table 2 for the two conditions we simulated:

WRMM RUN 1 - assumes the dam is built to the topographic limit (1113 m).

WRMM RUN 4 - is an intermediate level #2 (1105 m).

We have also indicated characteristics for the actual maximum conditions achieved during the WRMM run 1 simulation. Although the maximum elevation was set to be 1113 m, over the 1970 - 1979 interval the water level never exceeded 1110 m.

In all instances average reservoir depth at FSL will be greater than 11 m, with a maximum depth greater than 29 m. At the maximum possible elevation (1113 m) approximately 45% of the flooded area will be contained at depths below 15 m (Figure 4), at the lower elevation 1105 the area below 15 m is roughly 35%.

Reservoir fluctuations through time (1970 - 1979) are projected to be minimal (less than 10 m) for WRMM runs 1 and 4 (Figure 5) and the water level fluctuations are about the same in each case. In a sequence of dry years (i.e. 1940's) the reservoir would reach much lower elevations (minimum 1082 m). Under these conditions the average water residence time and mean depths would be appreciably reduced.

Existing streamflows in the Milk River basin (Figure 6) are characterized by low flows in November through February. Flows increase during March and April due to snowmelt and local runoff. Maximum flows occur during May and June due to 1) rainfall events and 2) diversion of water from the St. Mary River. These high flows are generally sustained during July and

Table 2. General characteristics of proposed Milk River Reservoir assuming various elevations.

	Topographic Limit (WRMM #1 - FSL)	Topographic Limit (WRMM #1-ACTUAL)	Intermediate Level 2 (WRMM #4 -FSL)
Elevation (m)	1113	1110	1105
Capacity (m^3)	310×10^6	248×10^6	166×10^6
Area (m^2)	21.60×10^6	18.53×10^6	14.42×10^6
Avg. Depth (m)	14.4	13.4	11.5
Max Depth (m)	40	37	32
Flushing rate (1/yr)	-	1.18	1.82

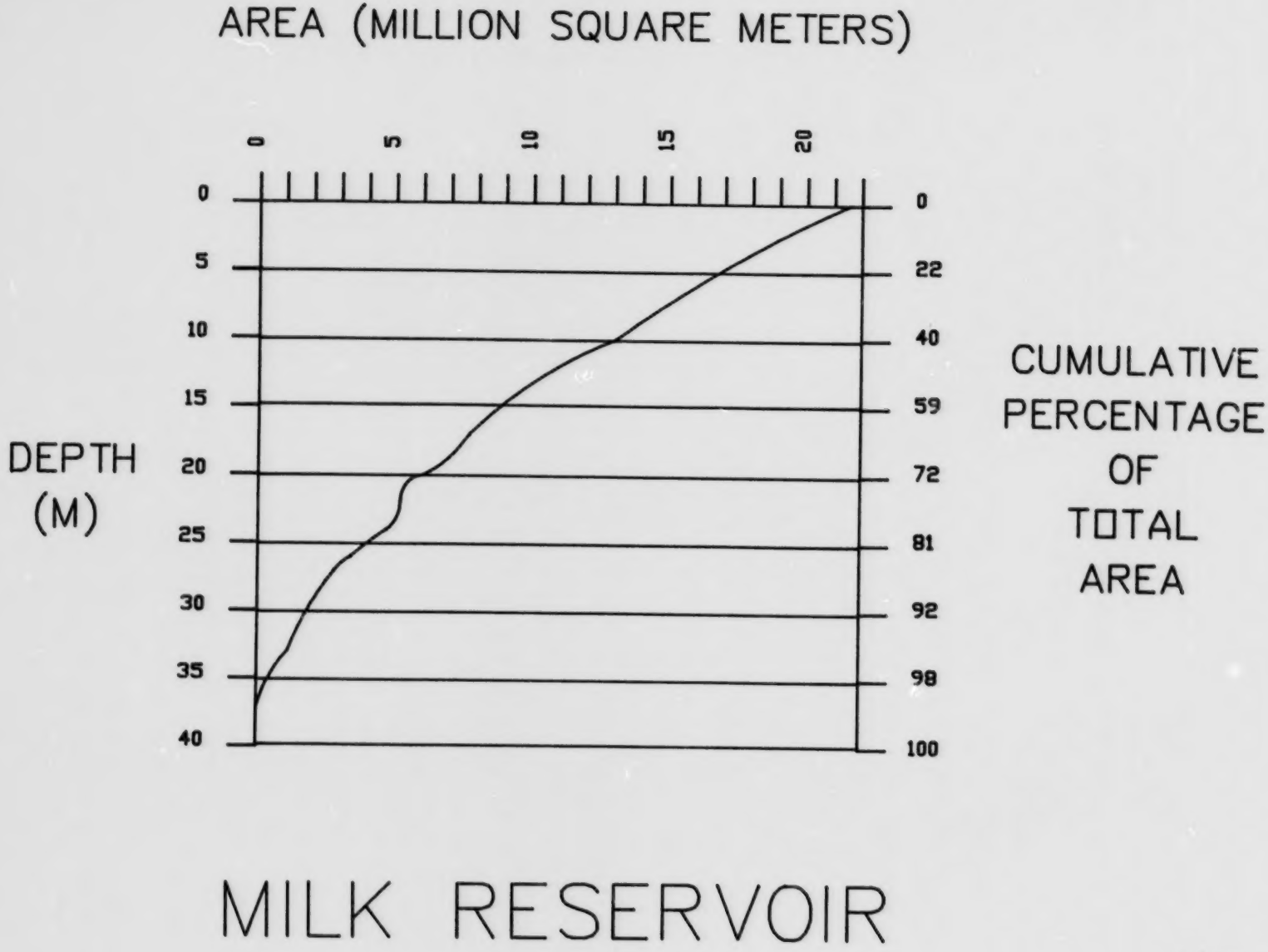

AREA (MILLION SQUARE METERS)
0
5
10
15
20
DEPTH (M)
0
5
10
15
20
25
30
35
40
0
22
40
59
72
81
92
98
100
CUMULATIVE PERCENTAGE OF TOTAL AREA
MILK RESERVOIR

Figure 4.

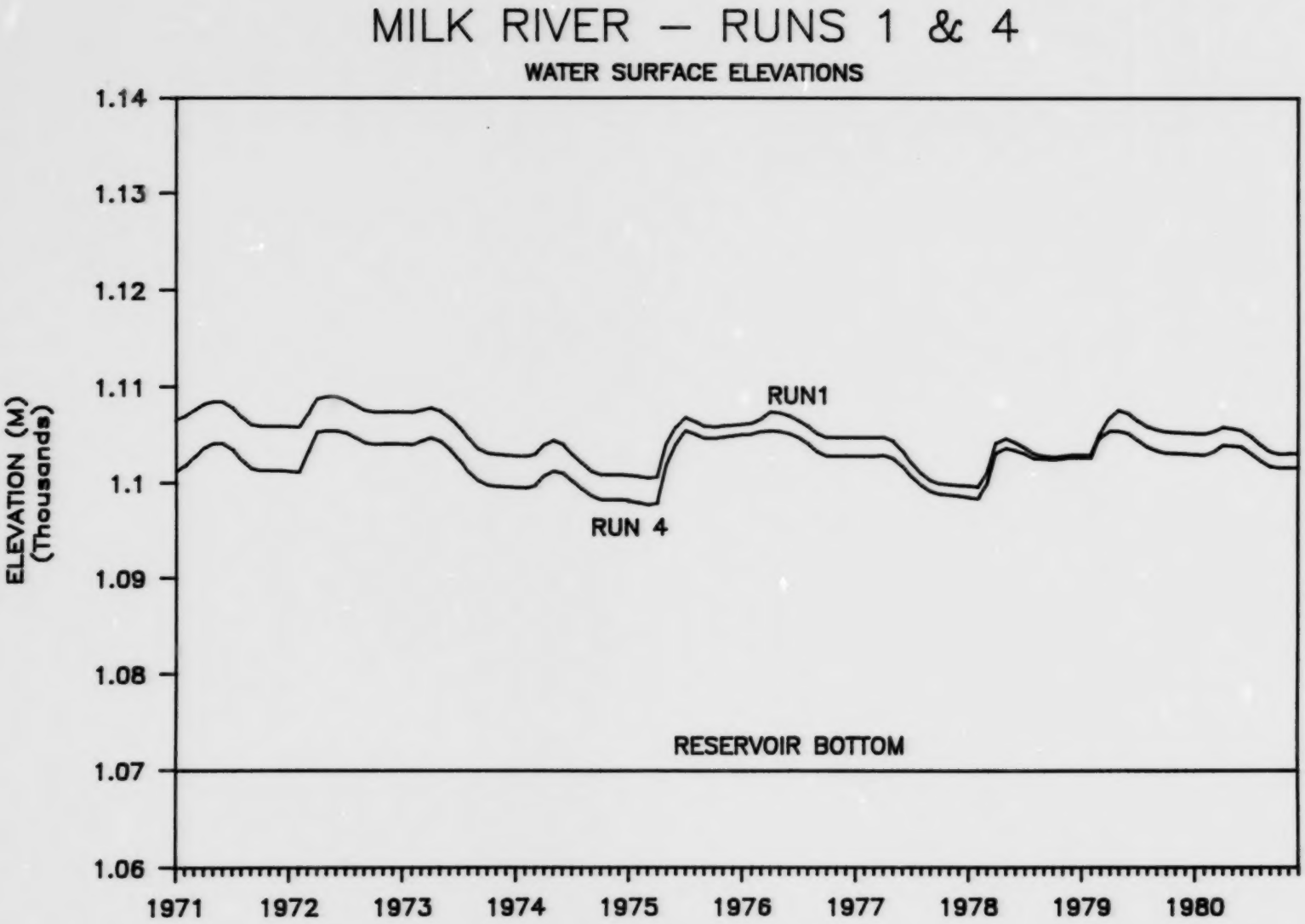

MILK RIVER – RUNS 1 & 4
WATER SURFACE ELEVATIONS
1.14
1.13
1.12
1.11
1.1
1.09
1.08
1.07
1.06
ELEVATION (M)
(Thousands)
RUN1
RUN 4
RESERVOIR BOTTOM
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1971–1980 BY MONTH

Figure 5.

EFFECT OF RESERVOIR ON DOWNSTREAM FLOW REGIME, LINES INDICATE MONTHLY AVERAGE FLOWS (1970–1979) AT MILK RIVER TOWN

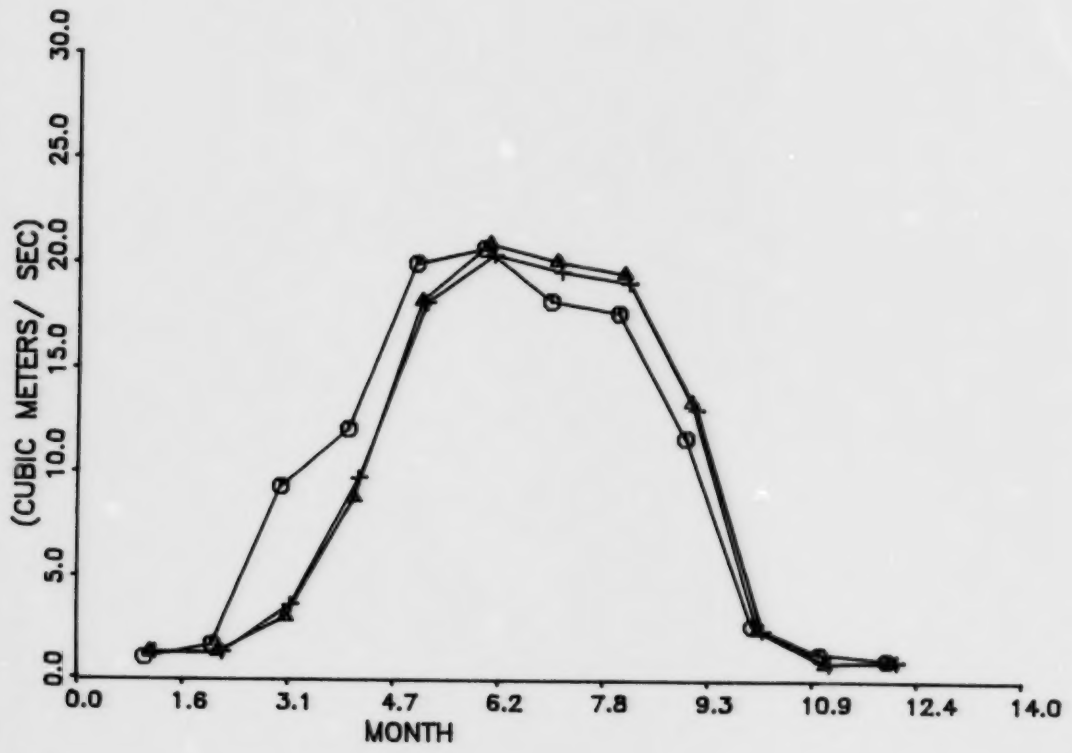


Figure 6.

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August by the continued diversion, and drop thereafter as the St. Mary diversion is shut off.

After reservoir construction the flow pattern will not change drastically. March, April and May flows downstream of the reservoir will be reduced slightly, while summer flows will be increased to a minor extent. There is almost no difference in downstream flows between WRMM runs 1 and 4.

The average flushing rate (1970 - 1979) is 1.18 times per year for WRMM run 1 and 1.82 times per year for WRMM run 4. More specifically the average dilution ratio is very low for the October to March period (Table 3). Summer values (May to August) average approximately 20% of reservoir capacity for run 1 and 30% for run 4.

3.2 THERMAL REGIME

We did not simulate temperatures for the reservoir or the river, and as such the comments made here are based upon experience with other reservoirs in southern Alberta, and the general literature. Quantitative prediction of thermal gradients and circulation patterns could be estimated with a model like LARM (Hamilton et al 1986).

The general morphometry of the Milk Reservoir is not that different from the Dickson Reservoir or the Oldman River Reservoir (under construction). Mean depths are all near 11 m and maximum depths exceed 30 m. Most lakes and offstream reservoirs in southern Alberta can be expected to stratify at depths below 15 m (Charlton 1985). In the case of the Milk reservoir 35% to 45% of the reservoir area will experience depths greater than 15 m. The LARM simulations forecast that the Oldman Reservoir should stratify (Hamilton et al, 1986), and monitoring results for the Dickson Reservoir indicate it does experience summer stratification (P. Mitchell, Alberta Environment, pers. comm.). In light of this, it is probable that the Milk River reservoir will also stratify during summer months.

Flushing rate and location of the outflow are two factors that strongly influence the thermal regime of onstream reservoirs. High seasonal

Table 3. Ratio of average monthly inflow volume to reservoir capacity expressed as a percentage.

	WRMM RUN #1	WRMM RUN #4
January	1	2
February	1	2
March	3	6
April	9	16
May	19	30
June	22	34
July	21	32
August	21	31
September	14	21
October	3	4
November	1	1
December	1	1

inflows, i.e. May, June snowmelt runoff, can limit the onset of normal thermal stratification until later in the season. The May - June inflows to the Milk are reduced relative to the Dickson and Oldman reservoirs, therefore stratification may commence earlier in June.

Surface or mid-depth withdrawals tend to favour development of a thermal gradient, whereas, bottom withdrawals can have a de-stabilizing effect. In the case of the Milk reservoir outflow rates are substantial and relatively constant for June through August. As such a bottom withdrawal may limit thermocline development, or degrade the extent and duration of it.

Since most of the inflow to the reservoir will be via the North Milk, the arm that extends up the Milk River valley will experience a reduced flushing rate. This could result in different thermal regimes in each arm. The North Milk arm could conceivably be cooler and more subject to interflow or underflow of incoming water.

Reservoirs generally dampen annual downstream river temperature fluctuations. Summer maximum temperatures below the dam are generally reduced, and shifted until later in the season. Similarly, fall cooling is often delayed until later in the fall and the winter minimum often remains between one and four ^{o}C. With distance from the reservoir, temperatures tend to return to a more normal pattern as the system re-equilibrates to ambient air temperatures. The precise nature of the general effect described here is partially dependent upon outflow location (surface, mid or bottom).

There will be a zone downstream of the reservoir where ice cover does not form during winter months. The length of the open water zone can be estimated with an ice model.

3.3 SUSPENDED SOLIDS

Section 3.1 describes the differences between WRMM runs 1 and 4 as to reservoir levels and downstream flow regime. The resultant differences in downstream river water quality are also minor. The comparison between runs is graphically presented in Appendix 2. Since the variation between runs is

subtle subsequent discussion of downstream water quality refers to run 1 only, and by inference also applies to run 4.

Suspended solid levels in the eastern portion of the Milk River Basin have historically been high, and cited as a factor limiting aquatic life (A.A. Aquatic Research 1986). During WQPM model calibration non-filterable residue (NFR) concentrations in the headwater and tributary inflows could not account for the observed NFR patterns at eastern crossing (Figures 8 - 11). It was necessary to define substantial diffuse source inputs, assumed to be due to bank slumping and possible channel erosion or re-suspension. The historical monitoring data for Milk River at Milk River town are sketchy (Figure 8), but imply most of the diffuse NFR loading occurs downstream of that location. The 1986 sampling program also infers that much of the NFR diffuse source loading occurs downstream of the confluence of the Milk and North Milk Rivers (Figure 12). However, during summer (July, August, September) there is a substantial increase in suspended solid concentrations along the North Milk, possibly caused by the high flows associated with the St. Mary diversion. This effect is less apparent during spring (April, May, June), and NFR concentrations remain low throughout the basin during fall and winter when flows are reduced. A sediment loading analysis being conducted by Water Survey of Canada, confirms that suspended solids are being generated along the North Milk, but most of the net annual loading still occurs downstream of the confluence (M. Spitzer, pers. comm.).

The WQPM simulation for WRMM run 1 forecasts little perceptible change in the NFR regime at Eastern Crossing (Figure 10). This is because most of the diffuse loading occurs being downstream of the dam site. With regulation, changes to the downstream flow regime are very subtle, therefore the erosion and slumping potential of the lower basin should not change drastically. Large amounts of bed degradation downstream of the dam will not likely occur as self armouring of the channel is expected to occur within a relatively short period of time (Winhold and Quazi, 1987).

Since the high suspended solid concentrations experienced at Eastern Crossing will not be input to the proposed reservoir, reservoir turbidity as caused by headwater inflows should remain moderately low,

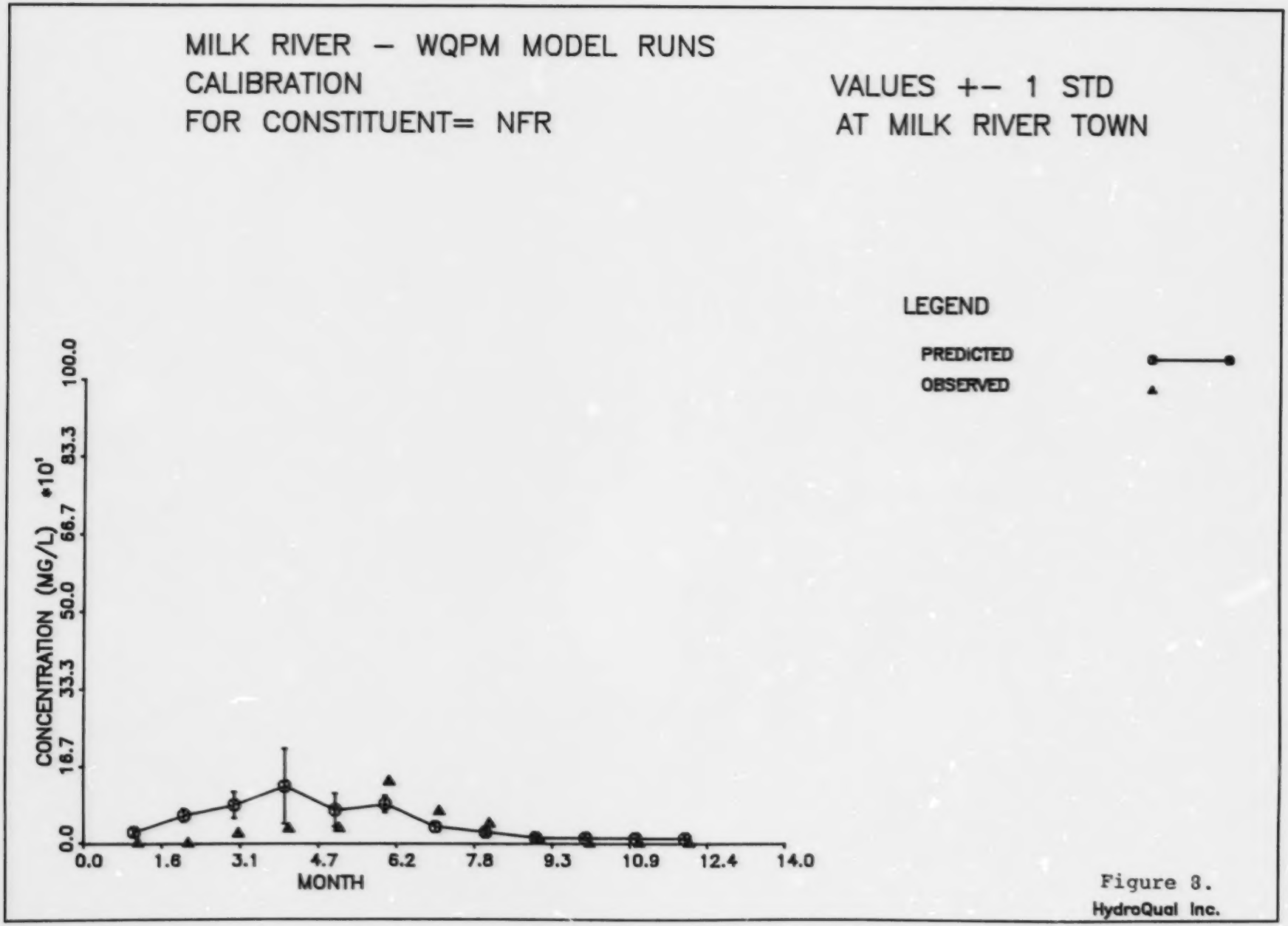

Figure 8.

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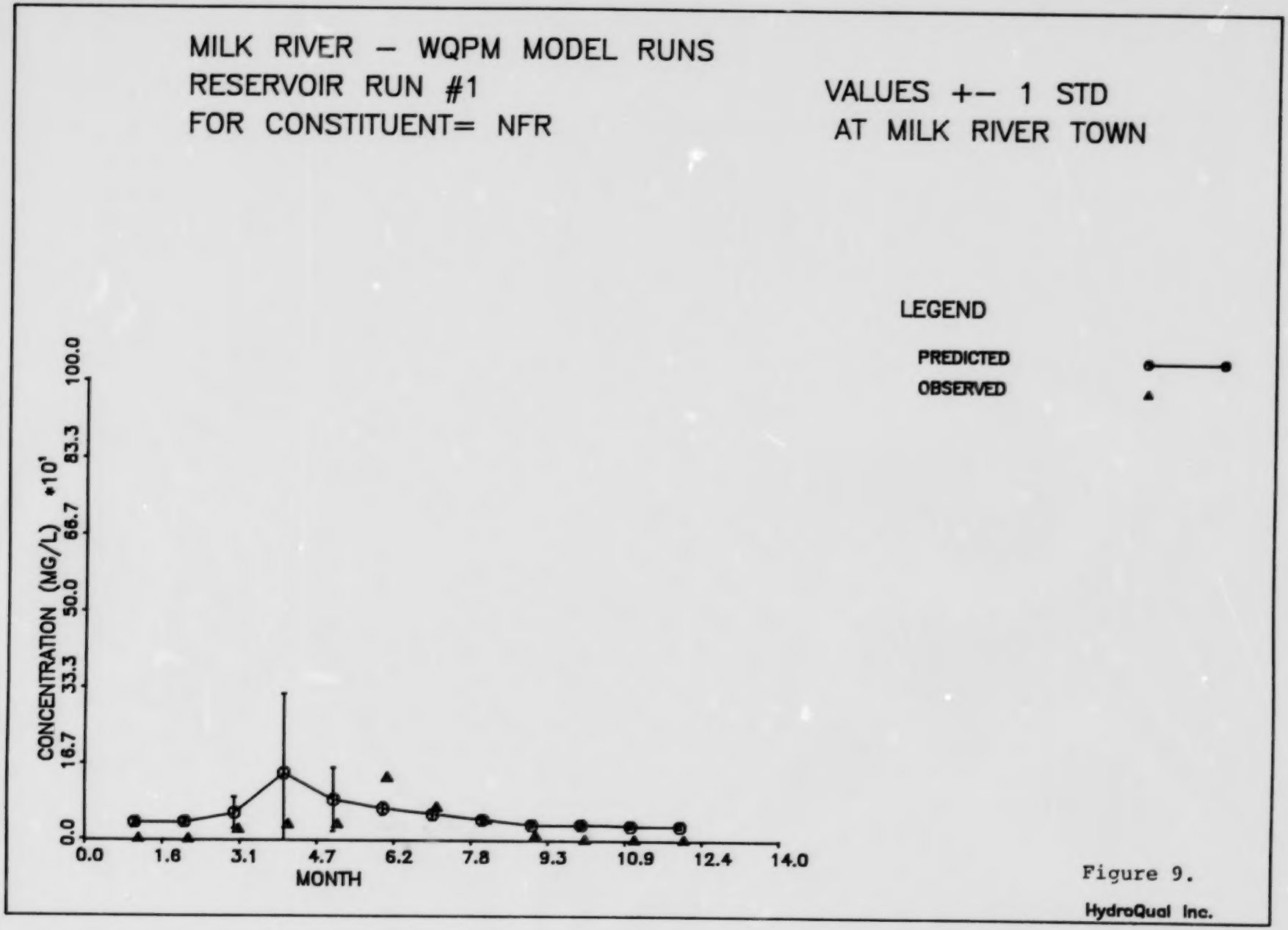

Figure 9.

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MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= NFR

VALUES +– 1 STD
AT EASTERN CROSSING

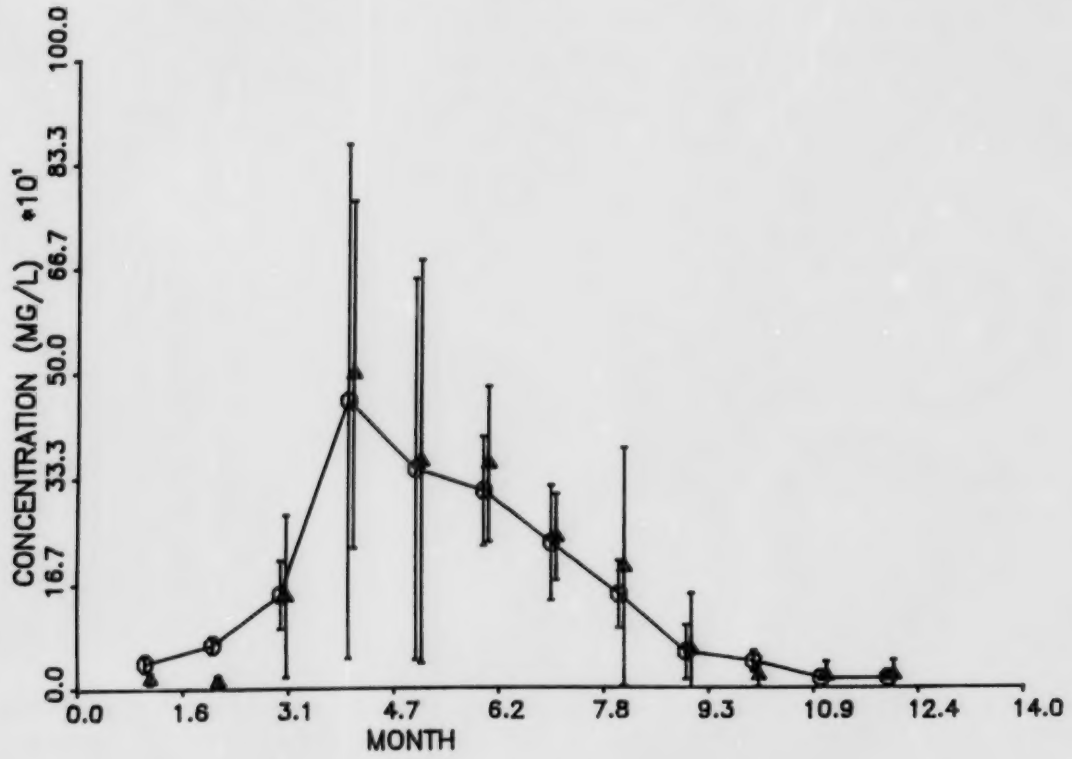

Figure 10.

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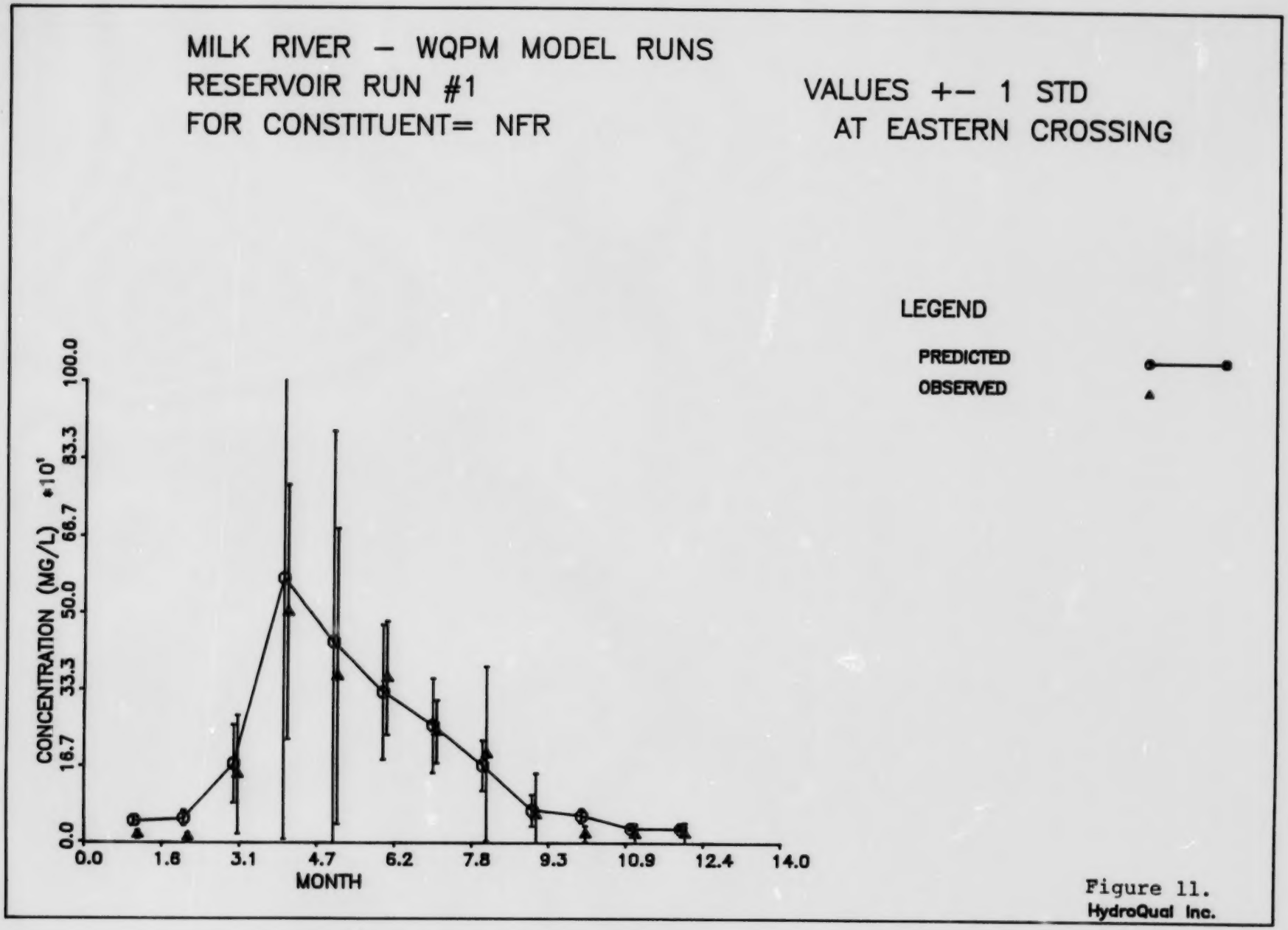

Figure 11.
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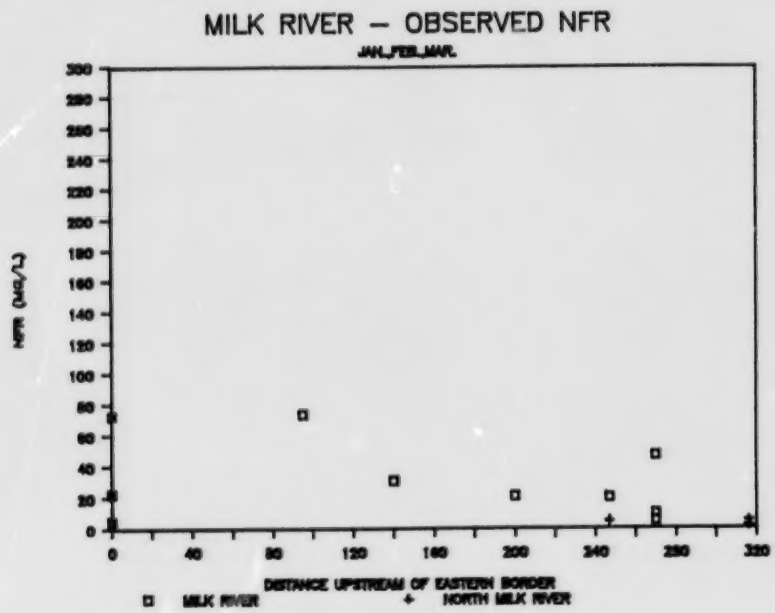
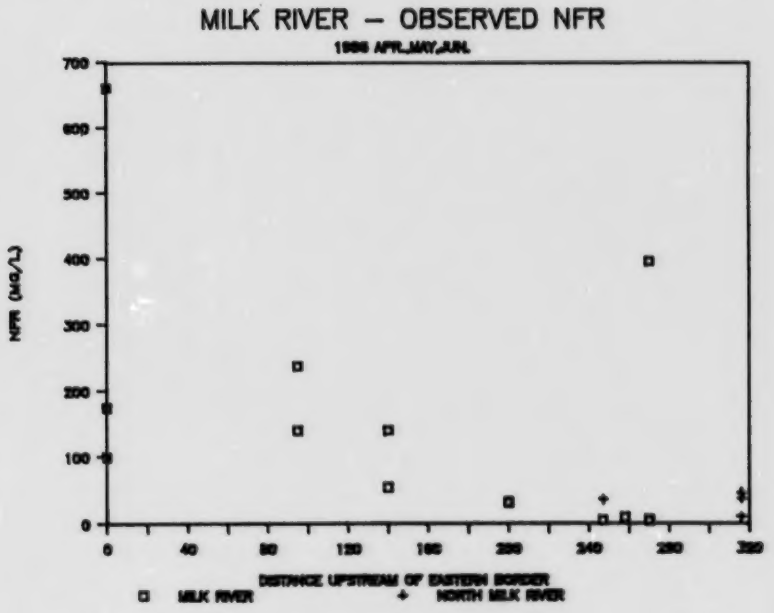
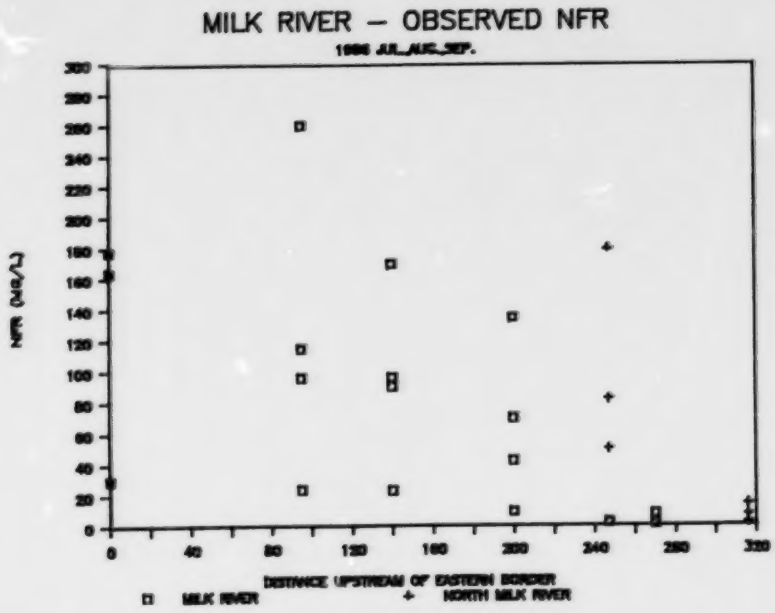

MILK RIVER – OBSERVED NFR
JAN_FEB_MAR.
NFR (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER


MILK RIVER – OBSERVED NFR
1986 APR_MAY_JUN.
NFR (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER


MILK RIVER – OBSERVED NFR
1986 JUL_AUG_SEP.
NFR (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER

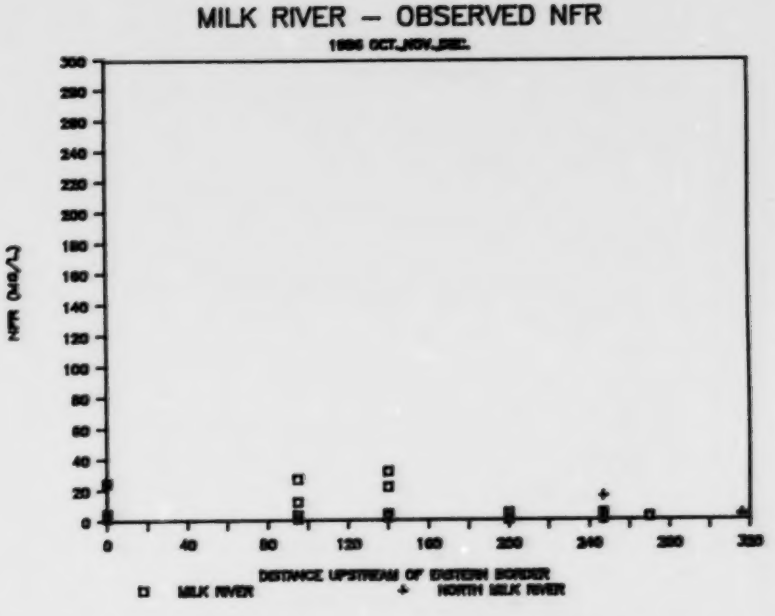

MILK RIVER – OBSERVED NFR
1986 OCT_NOV_DEC.
NFR (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER

Figure 12.

especially in the arm which extends up the Milk River valley. The turbidity of the North Milk arm could be somewhat elevated by the diversion related channel erosion. Possible secondary impacts on reservoir water clarity are bank slumping and wind induced shoreline erosion. Winhold and Quazi (1987) report that 30 to 40 percent of the reservoir shoreline may experience initial moderate tohigh erosion rates. This erosion will be most extensive along the east end of the reservoir. They further conclude that the erosion is only likely to significantly impact water quality during and immediately following severe storms.

3.4 MAJOR ION CHEMISTRY

3.4.1 CONDUCTIVITY

Conductivity is a measure of electrical conductance, and is a general indicator of total salinity (Figures 13 to 16). The existing condition is typified by high relative salinities during fall and winter. Concentrations decrease during March, April and May in response to dilution by local runoff. These low levels are sustained during June, July and August because of the St. Mary diversion which has a low total salt content.

It was difficult to calibrate winter conductivity using the flows predicted by the water balance model. During December, January and February the net diffuse source inflow from WRMM is usually negative, whereas, WQPM indicates there is a significant positive diffuse source salt loading over this entire interval. To calibrate, we arbitrarily set the winter diffuse source inflow downstream of the reservoir to 0.1 m^3/s. The actual net inflow forecast by Drainage Branch, Alberta Agriculture (J. Hendry, pers. comm.) amounts to 0.001 m^3/s. Although we have not accounted for salinity increases resulting from channel ice formation, it is obvious that the winter inflow quantity and quality are poorly known. More refined predictions of winter ion quality require more research on this issue.

Conductivity of the proposed reservoir will average less than 400 usie/cm, (Table 4) and the seasonal, as well as year to year variability, will be minimal (Appendix 1). Conductance levels in the lower Milk River

MILK RIVER – WQPM MODEL RUNS
CALIBRATION VALUES +– 1 STD
FOR CONSTITUENT= CONDUCTIVITY AT MILK RIVER TOWN

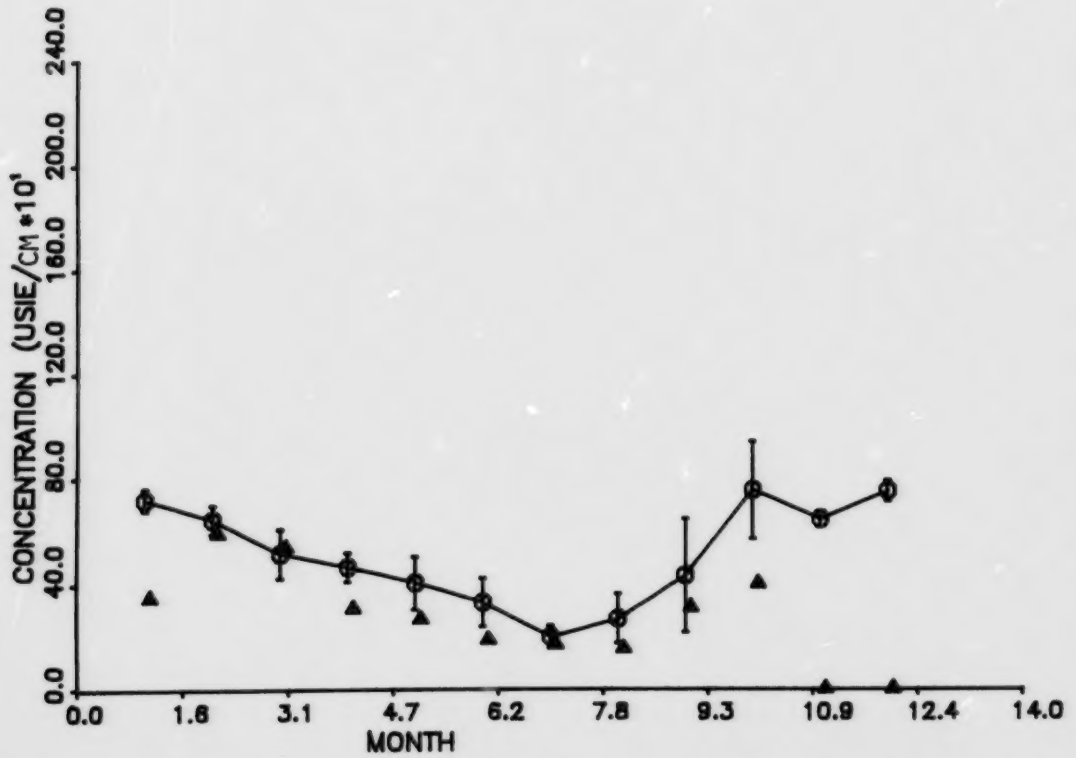


Figure 13.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= CONDUCTIVITY

VALUES +– 1 STD
AT MILK RIVER TOWN

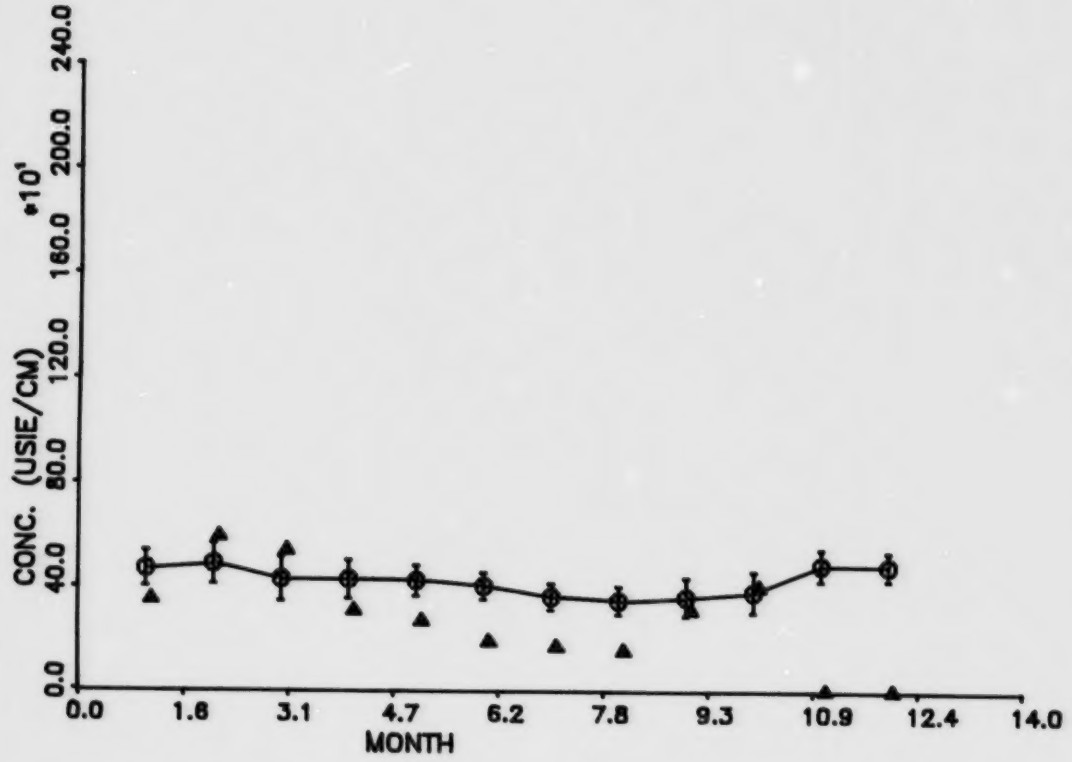


Figure 14.

HydroQual Inc.

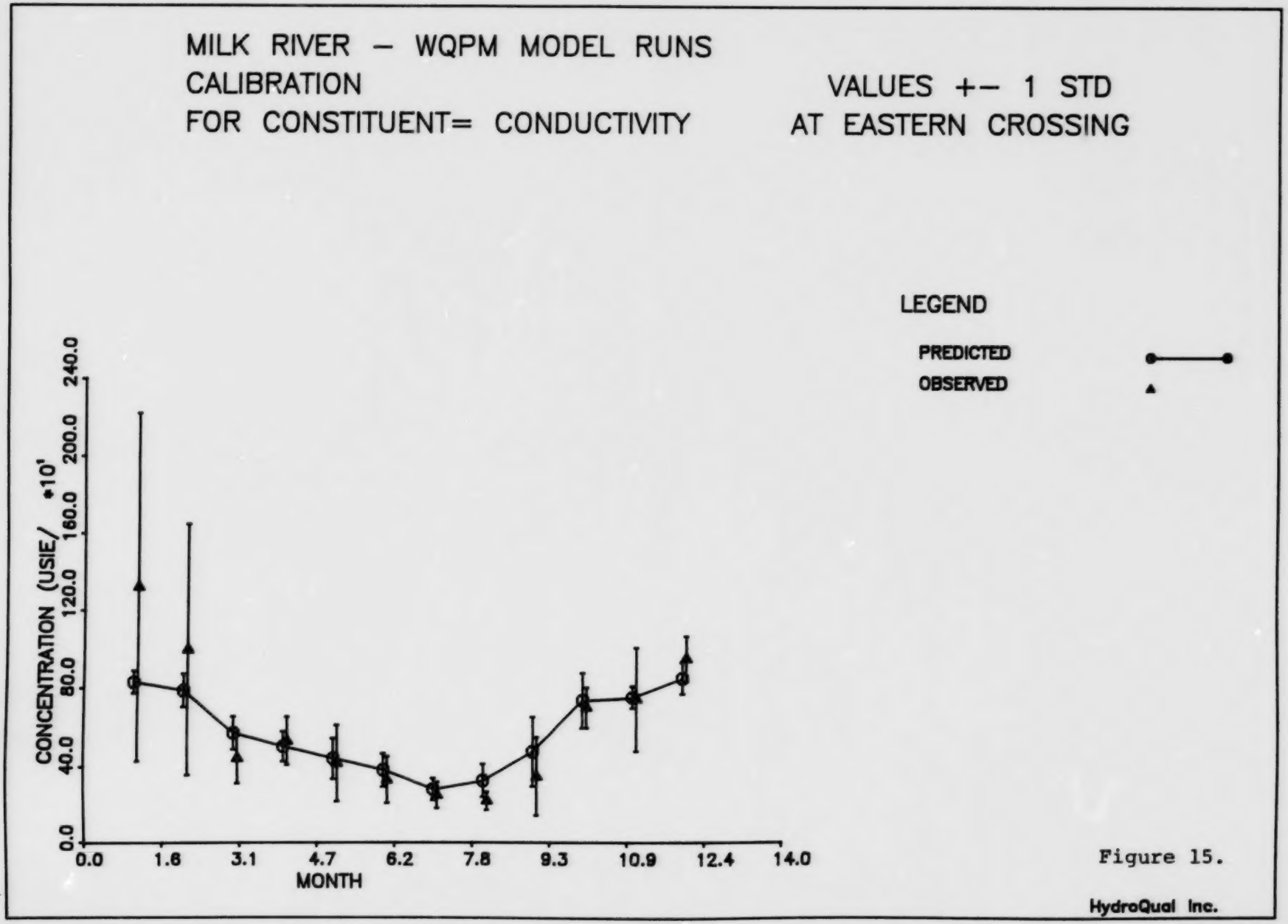

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= CONDUCTIVITY
VALUES +– 1 STD
AT EASTERN CROSSING
LEGEND
PREDICTED
OBSERVED
CONCENTRATION (USIE/ *10')
0.0
40.0
80.0
120.0
160.0
200.0
240.0
0.0
1.6
3.1
4.7
6.2
7.8
9.3
10.9
12.4
14.0
MONTH
HydroQual Inc.

Figure 15.

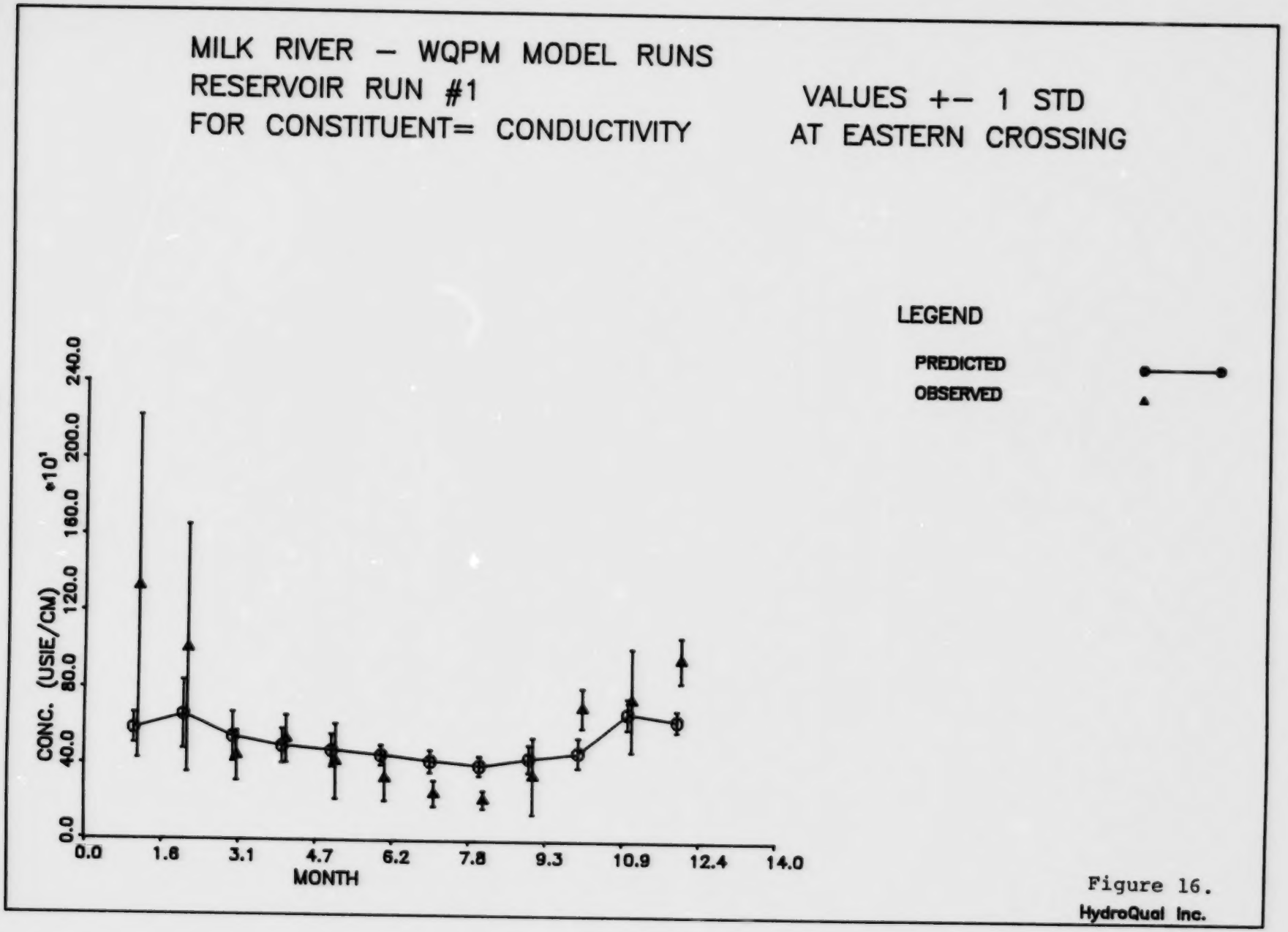


Figure 16.

HydroQual Inc.

Table 4. Predicted average reservoir concentrations for the period 1970 - 1979. Standard deviation indicated in brackets.

	WRMM RUN #1		WRMM RUN #4	
NFR (mg/l)	35	(7)	34	(9)
Conductivity (usie/cm)	387	(67)	385	(73)
Calcium (mg/l)	34	(2)	34	(3)
Magnesium (mg/l)	15	(2.5)	15	(1.8)
Sodium (mg/l)	29	(12)	29	(13)
Sulfate (mg/l)	36	(11)	35	(12)
Ammonia (mg/l)	0.027	(0.004)	0.027	(0.005)
Nitrate +Nitrite (mg/l)	0.124	(0.014)	0.126	(0.018)
Total Phosphorus (mg/l)	0.019	(0.011)	0.019	(0.012)
[1]Chlorophyll a (mg/l)	6.4		6.4	

[1]Predicted from TP using empirical model of Prepas and Trew (1983).

currently exceed 1000 usie/cm at low flows. Following reservoir construction conductivity fluctuations in the Milk River will be dampened. High winter values will be somewhat reduced, and concentrations for May through August will be increased. The winter improvements will be greatest near the dam, since the diffuse source inflows will still have an effect on reaches closer to the boundary.

3.4.2 MAJOR IONS

Table 4 presents reservoir summary statistics for calcium, magnesium, sodium and sulfate; while existing and future conditions downstream of the reservoir are presented in Figures 17 to 32. The patterns are generally similar to that of conductivity. The reservoir will tend to dampen the existing seasonal fluctuations in major ion chemistry. Summer values will increase somewhat, whereas the high winter concentrations will decline. The relative effect will be greatest closer to the dam, especially for those constituents which are characteristically high in groundwater, i.e. sodium and sulfate. Winter diffuse source inflows will still have a major influence on conditions at eastern crossing.

In the past, salinity has not been a major problem restricting use of the Milk River for any beneficial use. High salinities can impact on irrigation, however, Milk River values have historically been low during the irrigation season. Although summer salt concentrations will be increased by regulation, the levels throughout the basin should remain well within recommended safe limits.

We have not accounted for potential impacts of irrigation return-flow water on salinity of the lower Milk River. Potential impacts could be associated with 1) direct return of irrigation spill water, or 2) general long term alterations to the groundwater regime. Considering irrigation system expansion will most probably emphasize direct withdrawal for sprinklers and pivots, the first item is likely not a major issue unless conventional irrigation canal systems are developed; it is beyond the scope of this study to address the latter item, which is much more difficult to quantify.

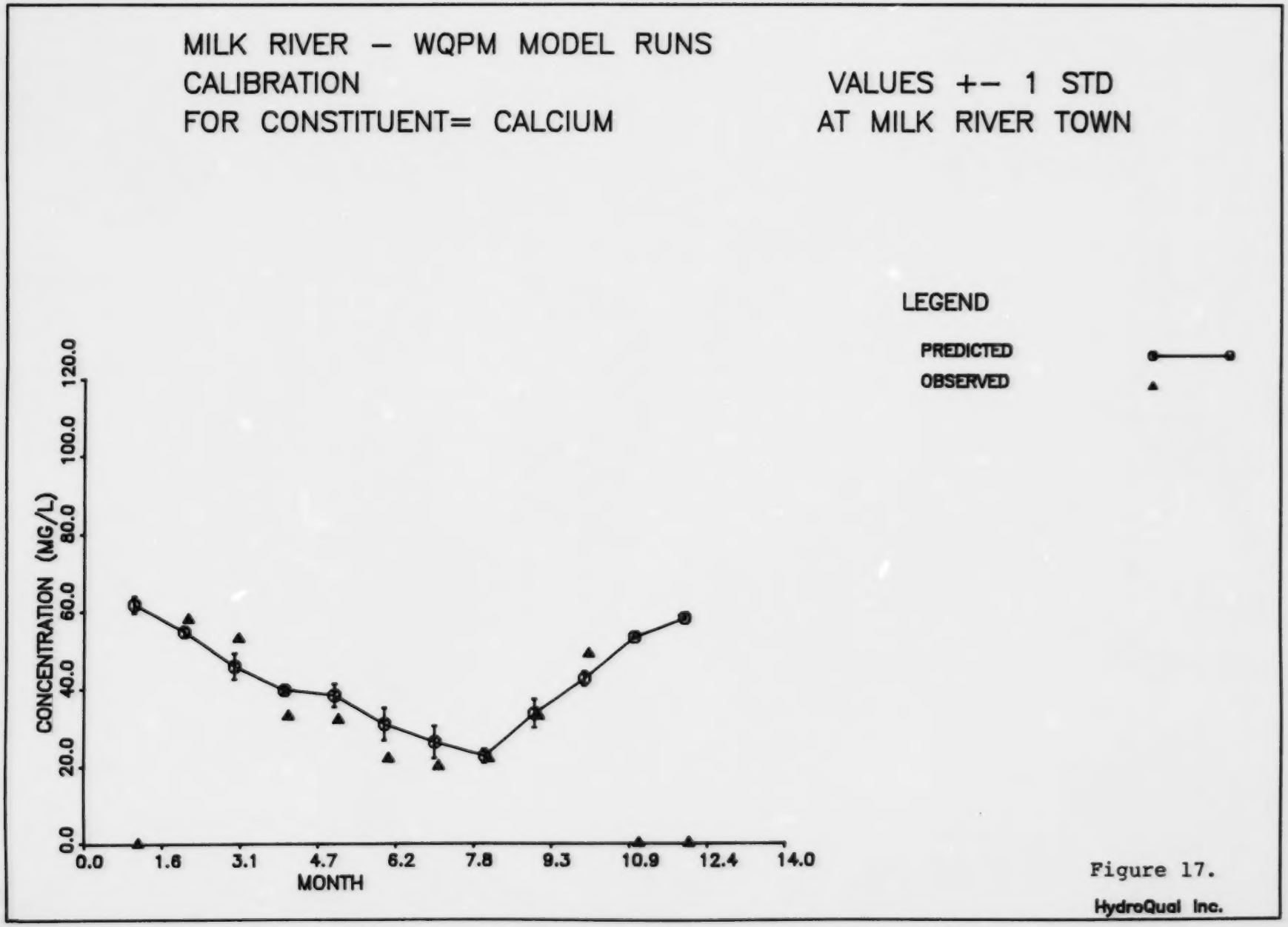

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= CALCIUM
VALUES +– 1 STD
AT MILK RIVER TOWN
LEGEND
PREDICTED
OBSERVED
CONCENTRATION (MG/L)
0.0
20.0
40.0
60.0
80.0
100.0
120.0
0.0
1.6
3.1
4.7
6.2
7.8
9.3
10.9
12.4
14.0
MONTH
HydroQual Inc.

Figure 17.

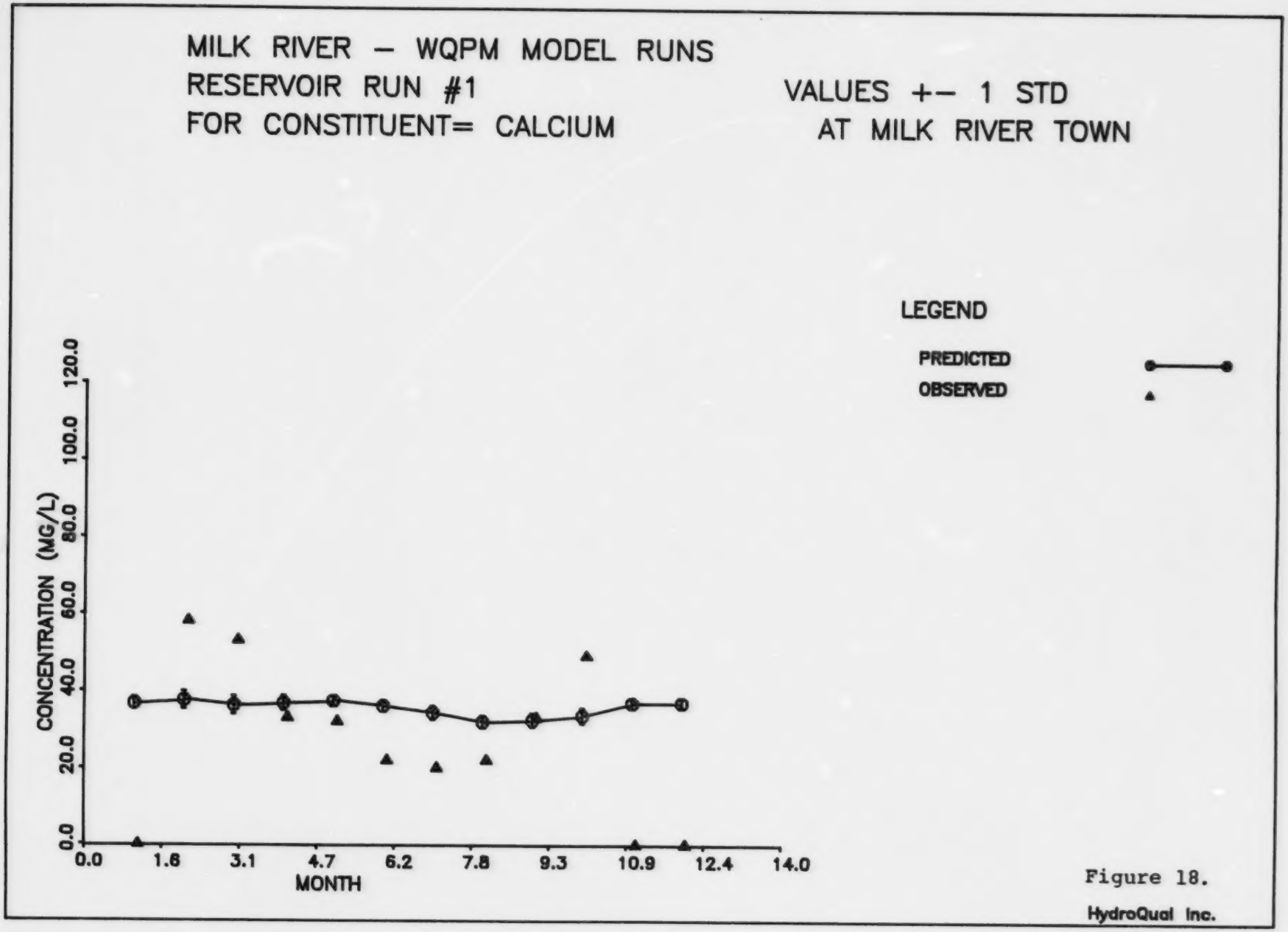


Figure 18.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= CALCIUM

VALUES +– 1 STD
AT EASTERN CROSSING

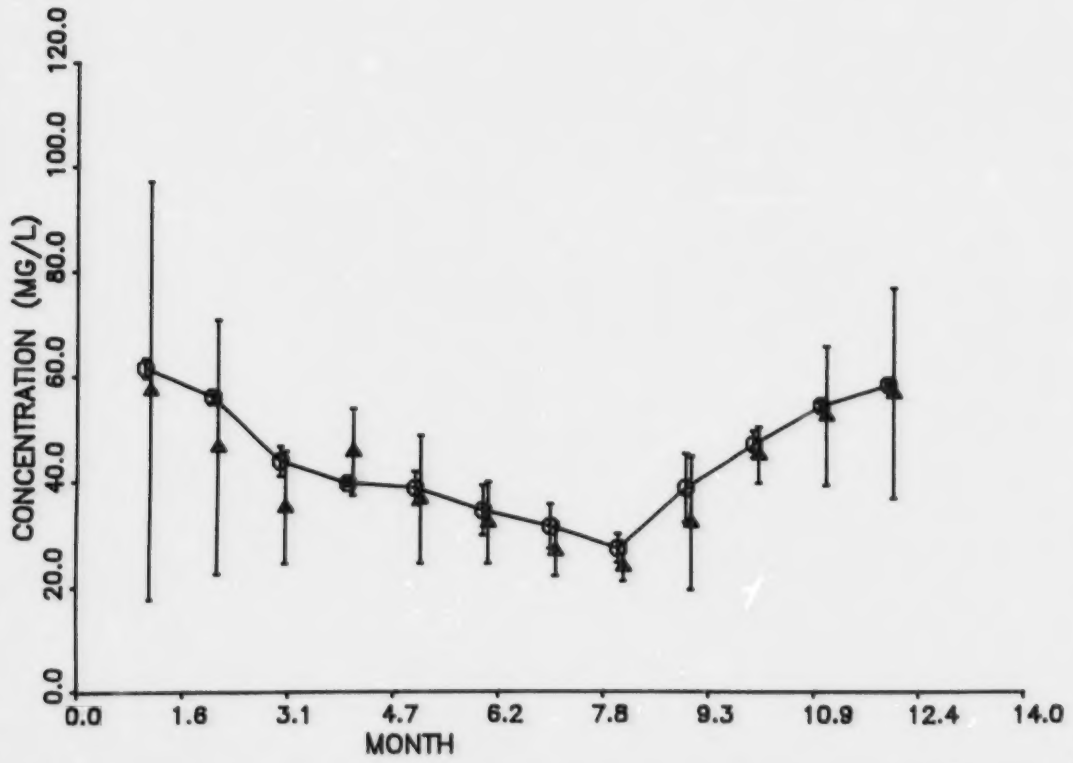


Figure 19.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= CALCIUM

VALUES +– 1 STD
AT EASTERN CROSSING

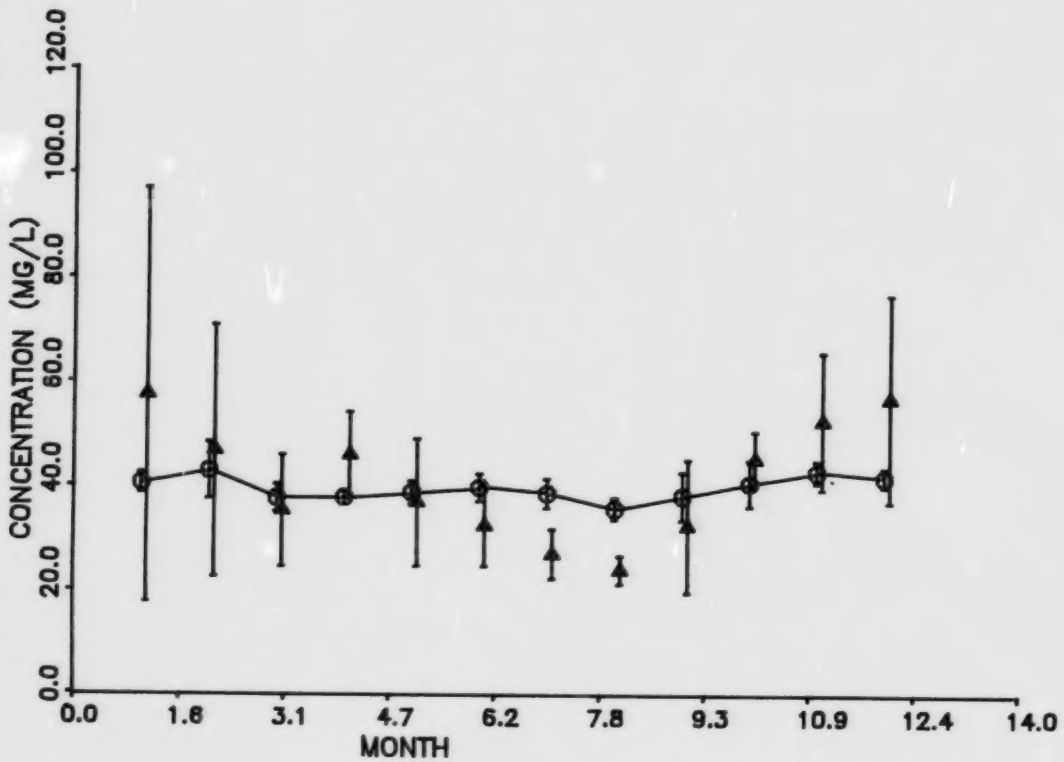


Figure 20.

HydroQual Inc.

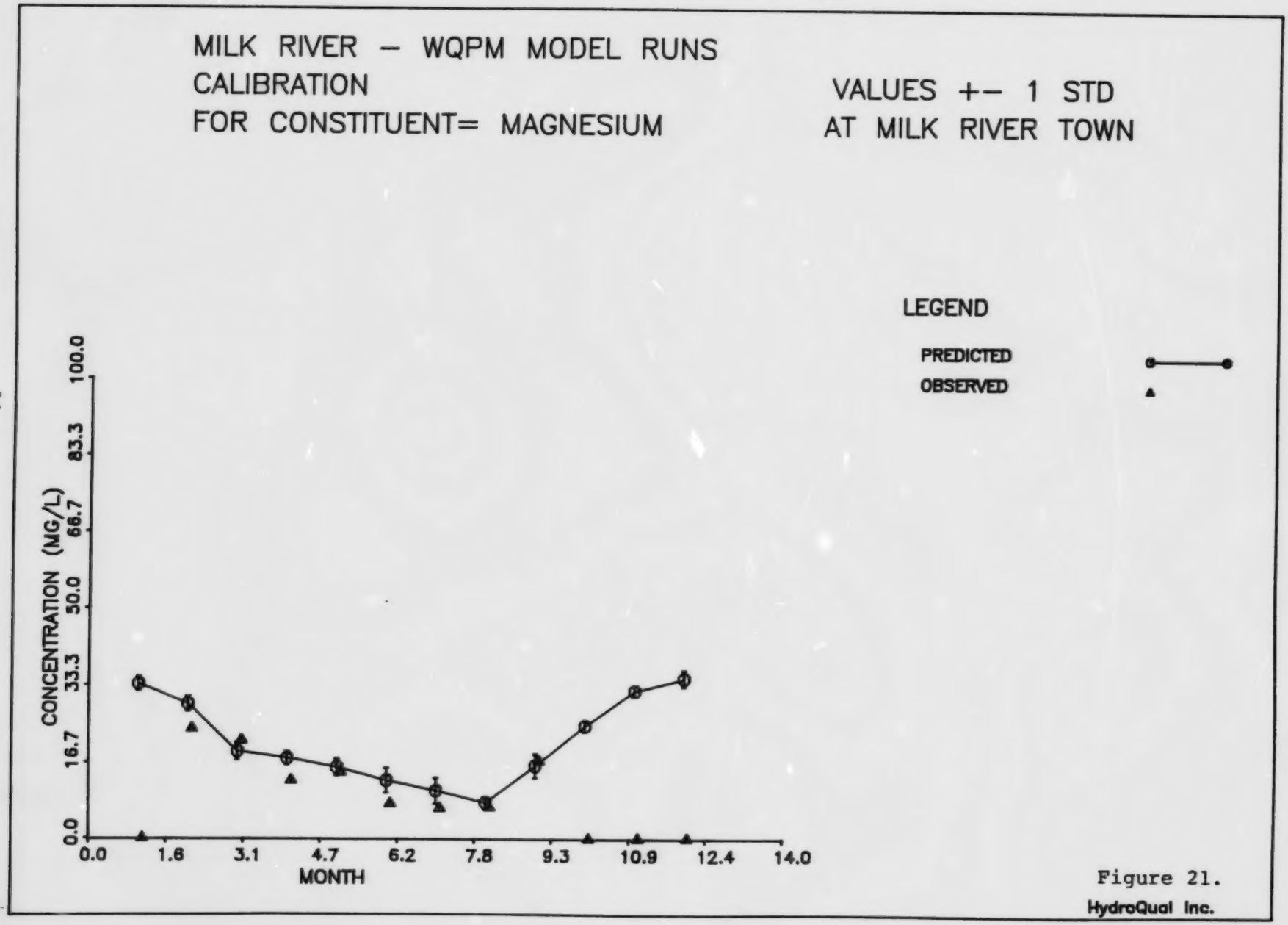


Figure 21.

HydroQual Inc.

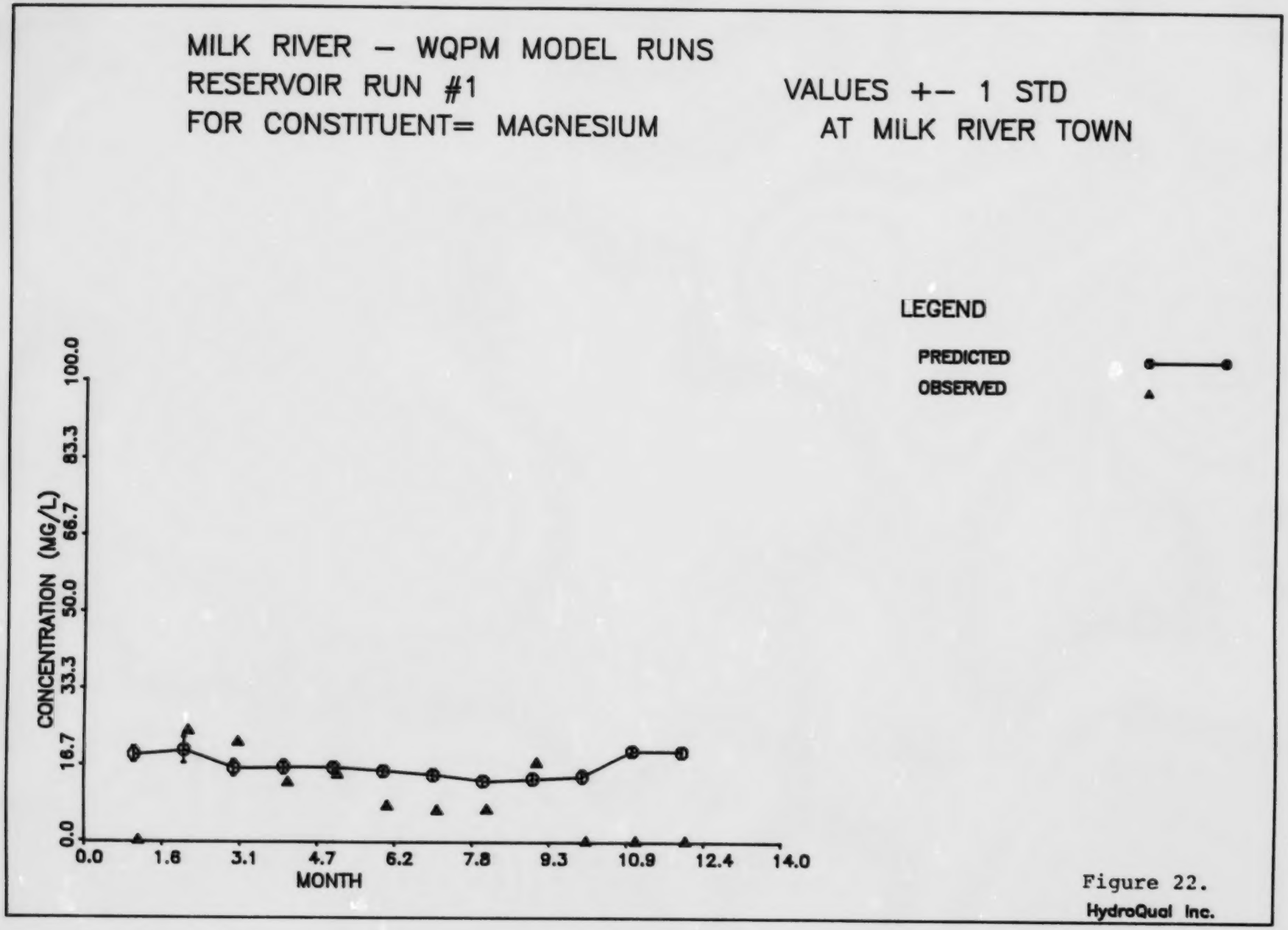
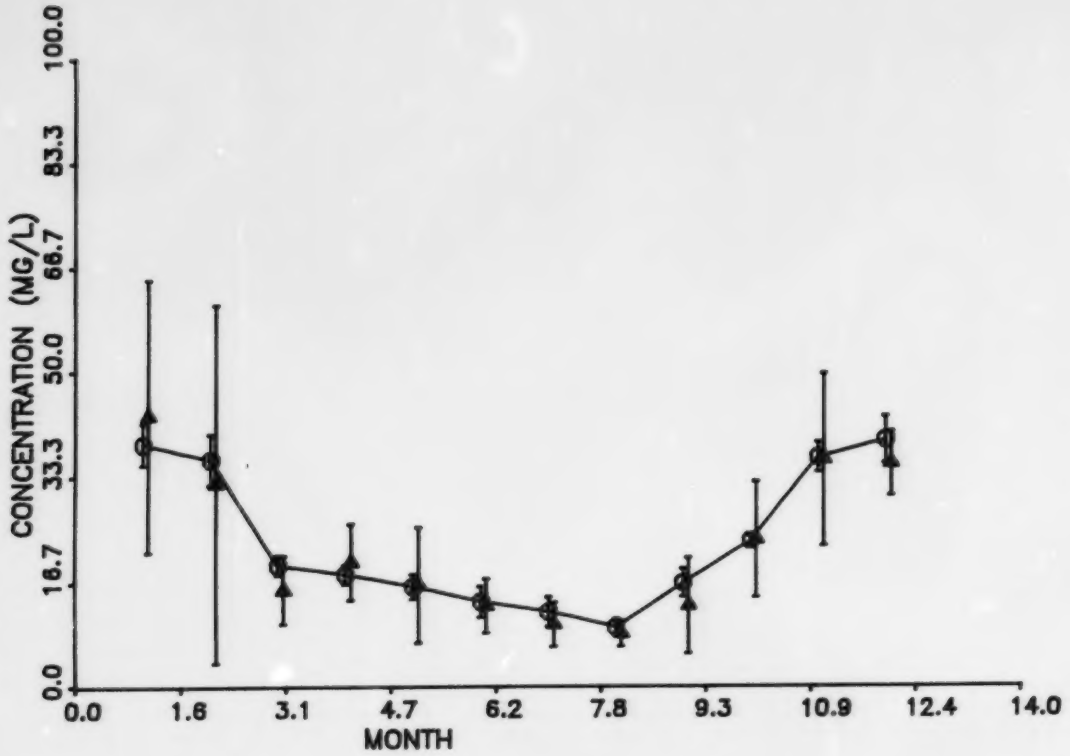


Figure 22.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= MAGNESIUM

VALUES +– 1 STD
AT EASTERN CROSSING



LEGEND

PREDICTED

OBSERVED

Figure 23.
HydroQual Inc.

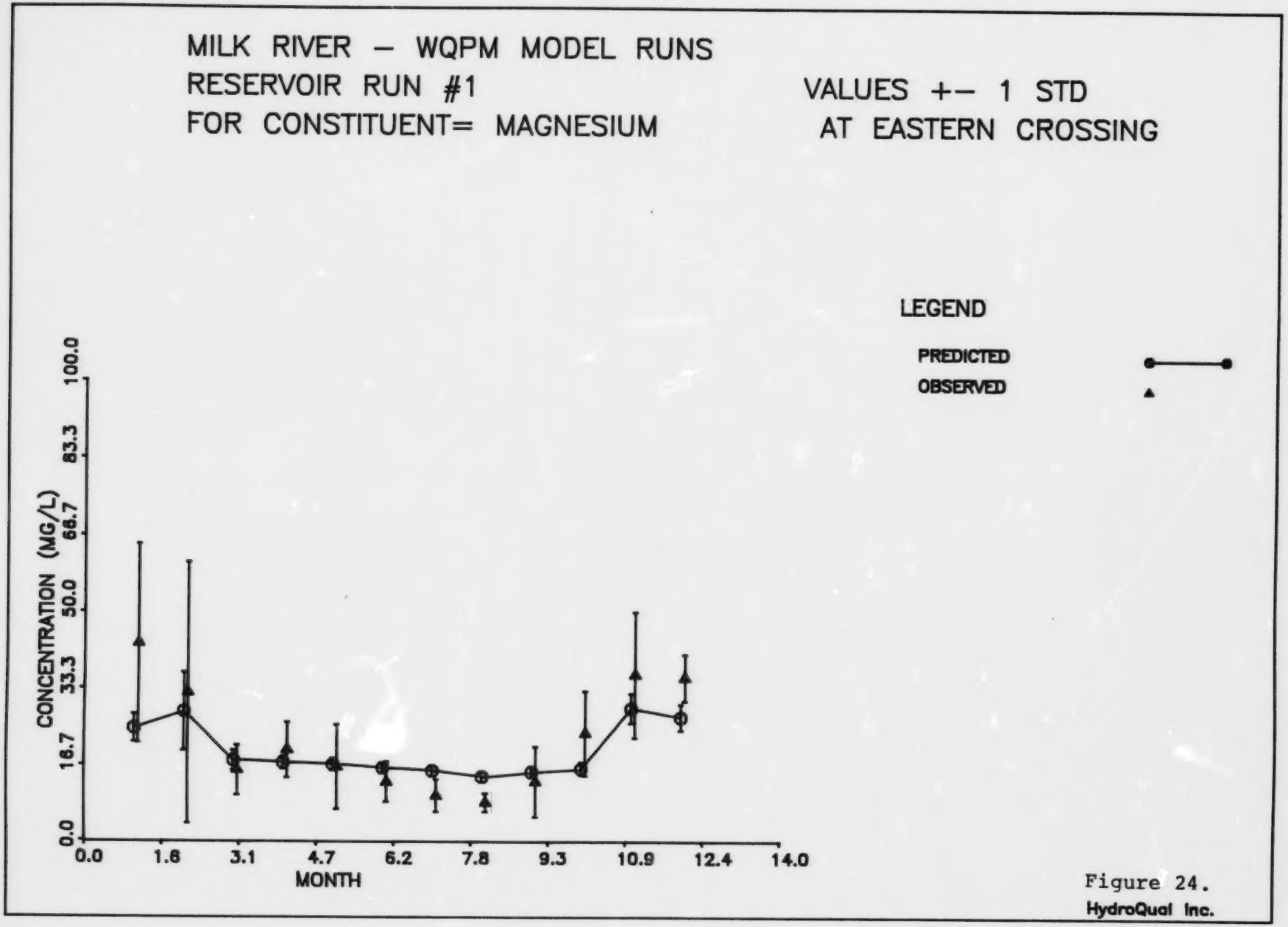


Figure 24.
HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= NA

VALUES +– 1 STD
AT MILK RIVER TOWN

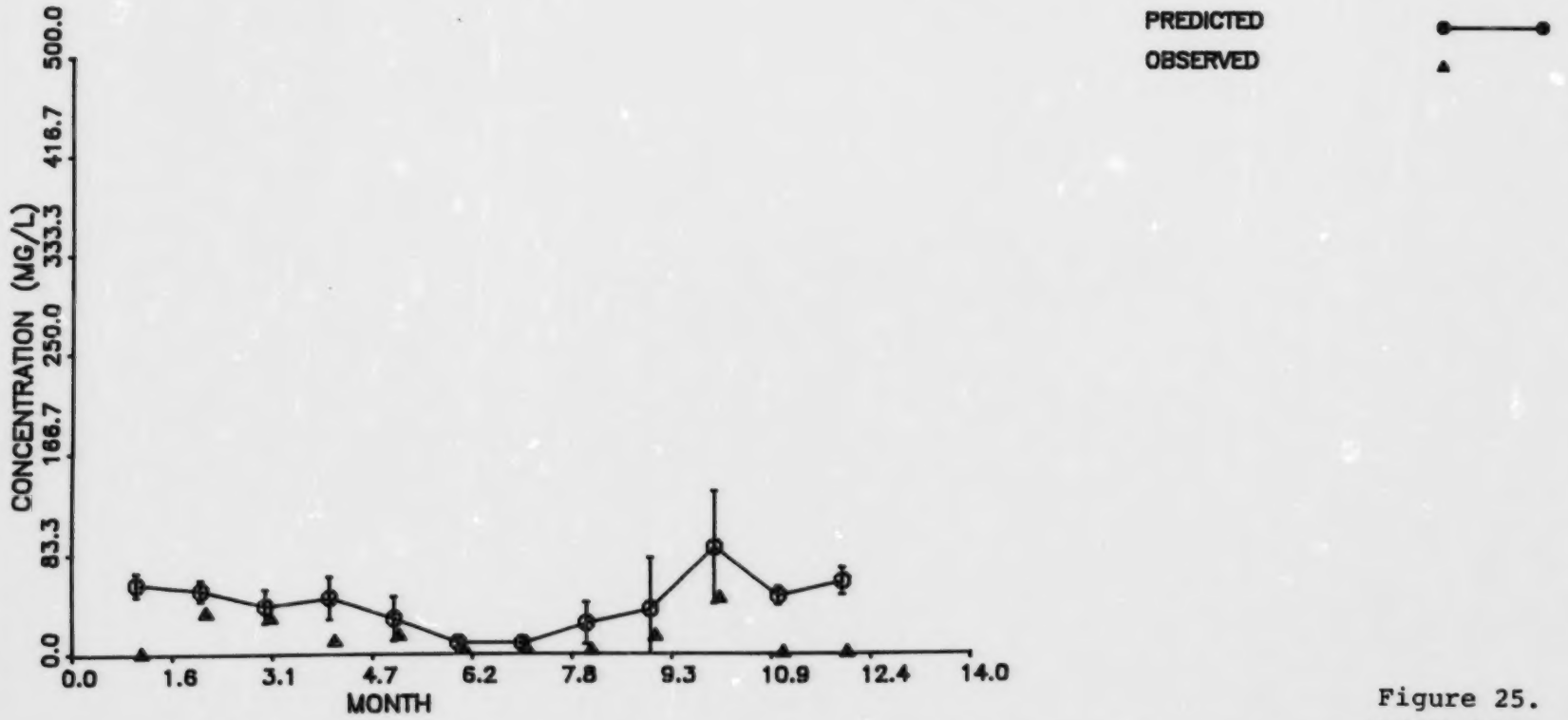


Figure 25.
HydroQual Inc.

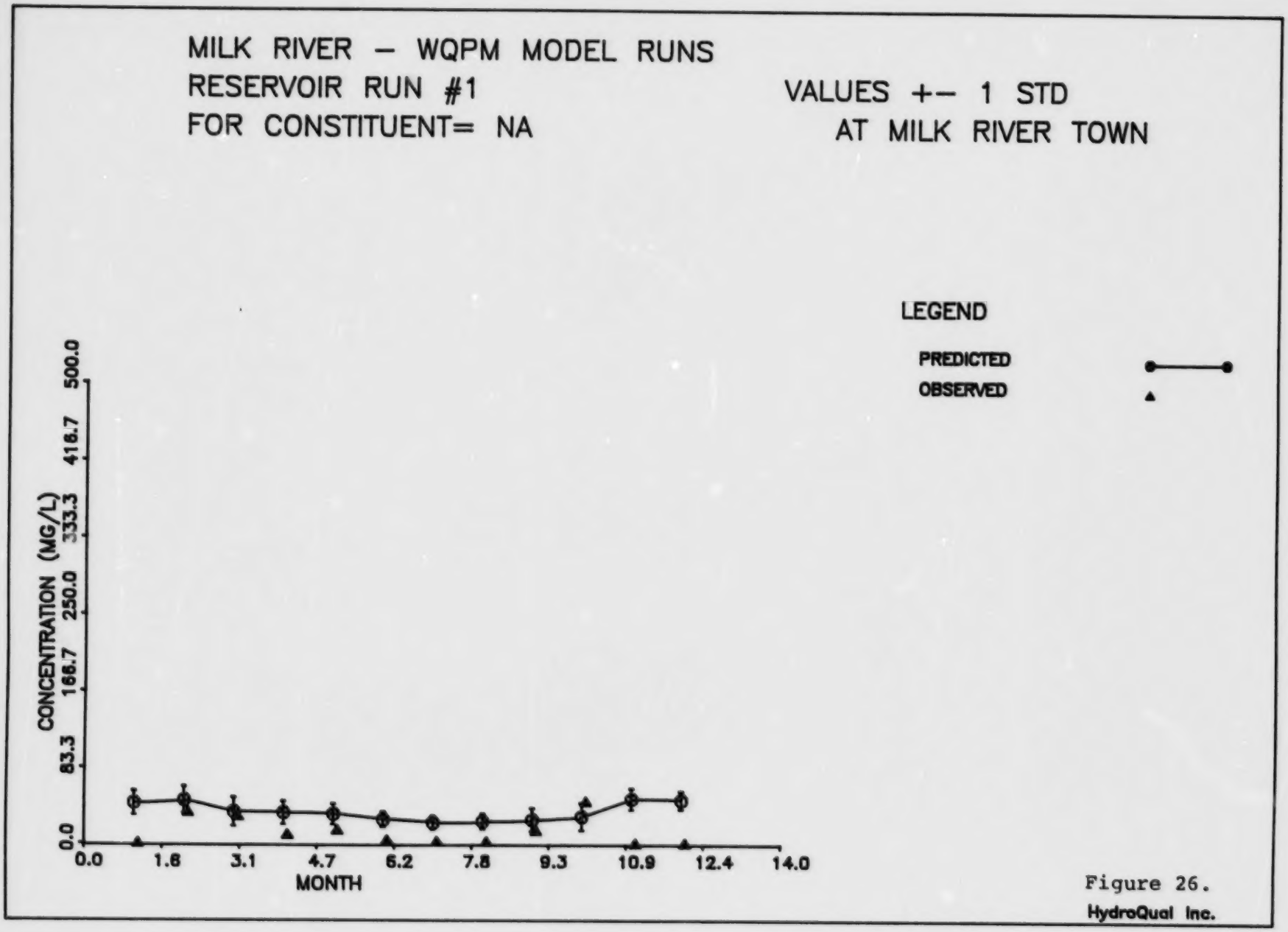


Figure 26.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= NA

VALUES +– 1 STD
AT EASTERN CROSSING

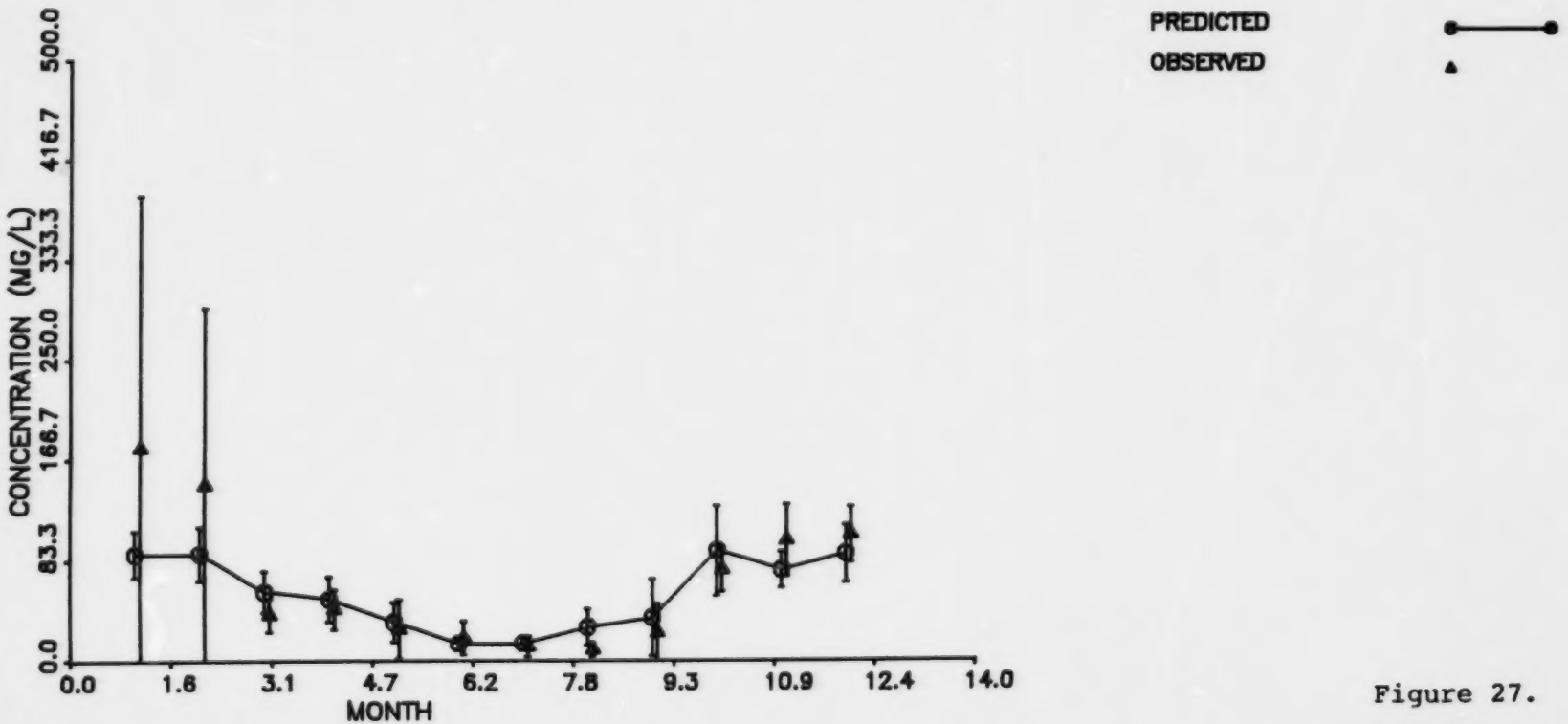


Figure 27.

HydroQual Inc.

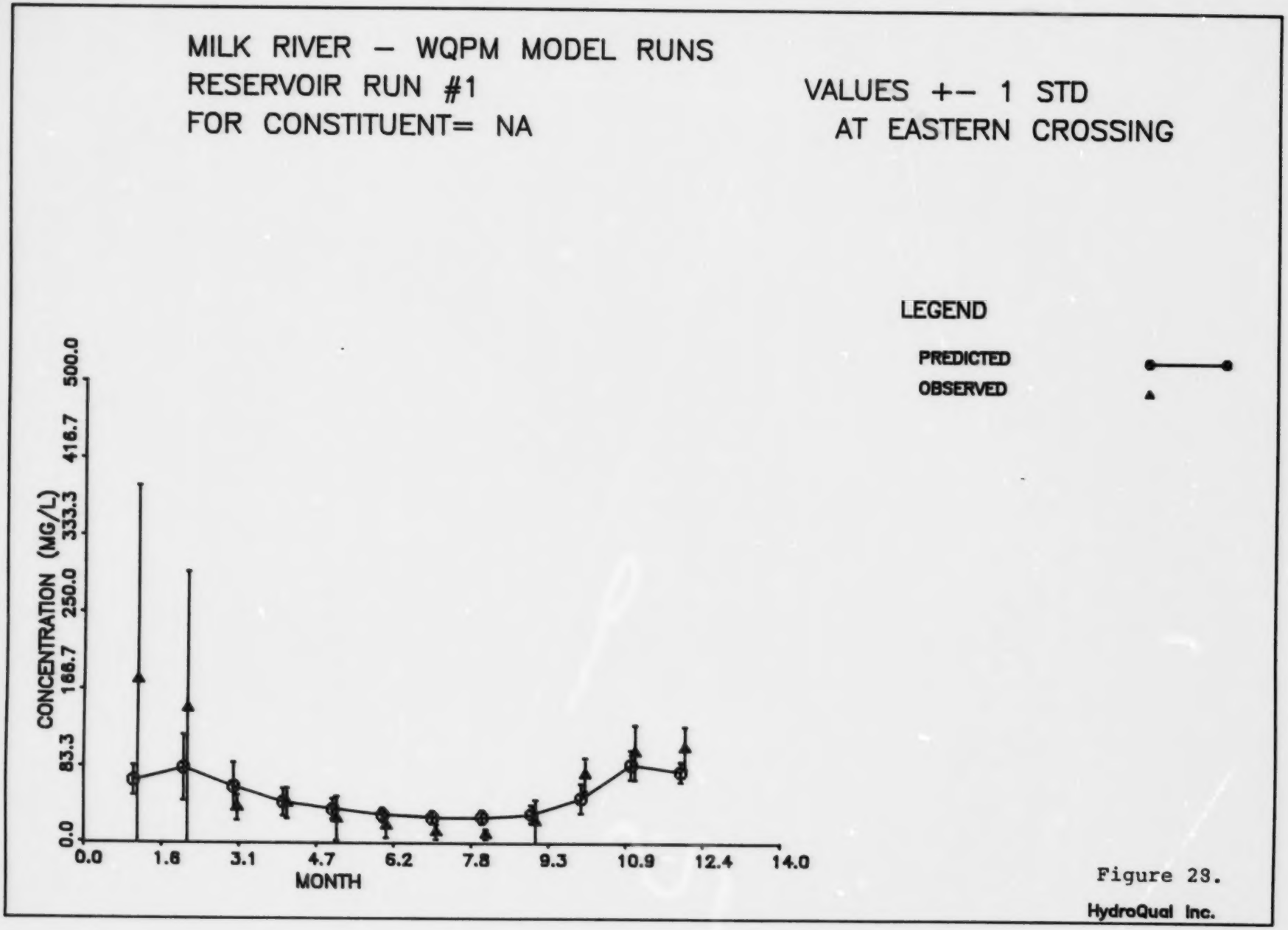


Figure 28.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= SO4

VALUES +– 1 STD
AT MILK RIVER TOWN

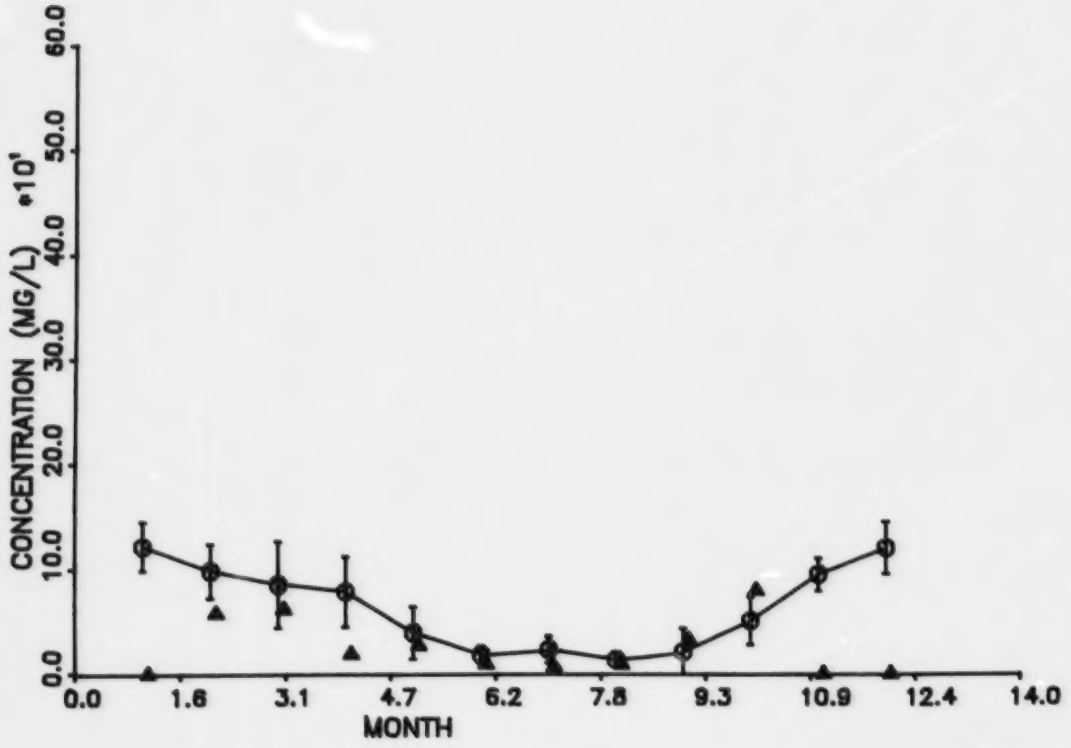


Figure 29.

HydroQual Inc.

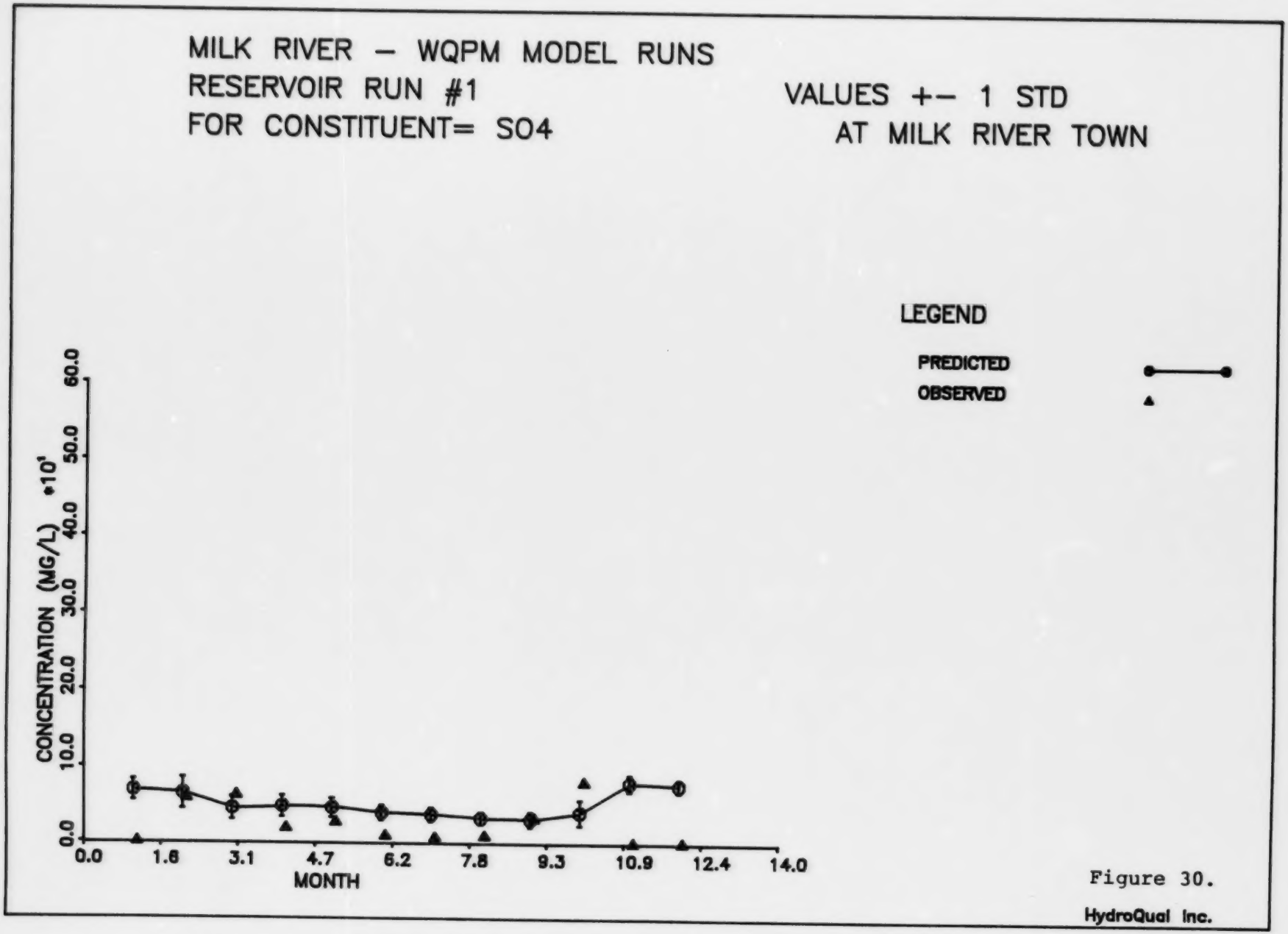


Figure 30.

HydroQual Inc.

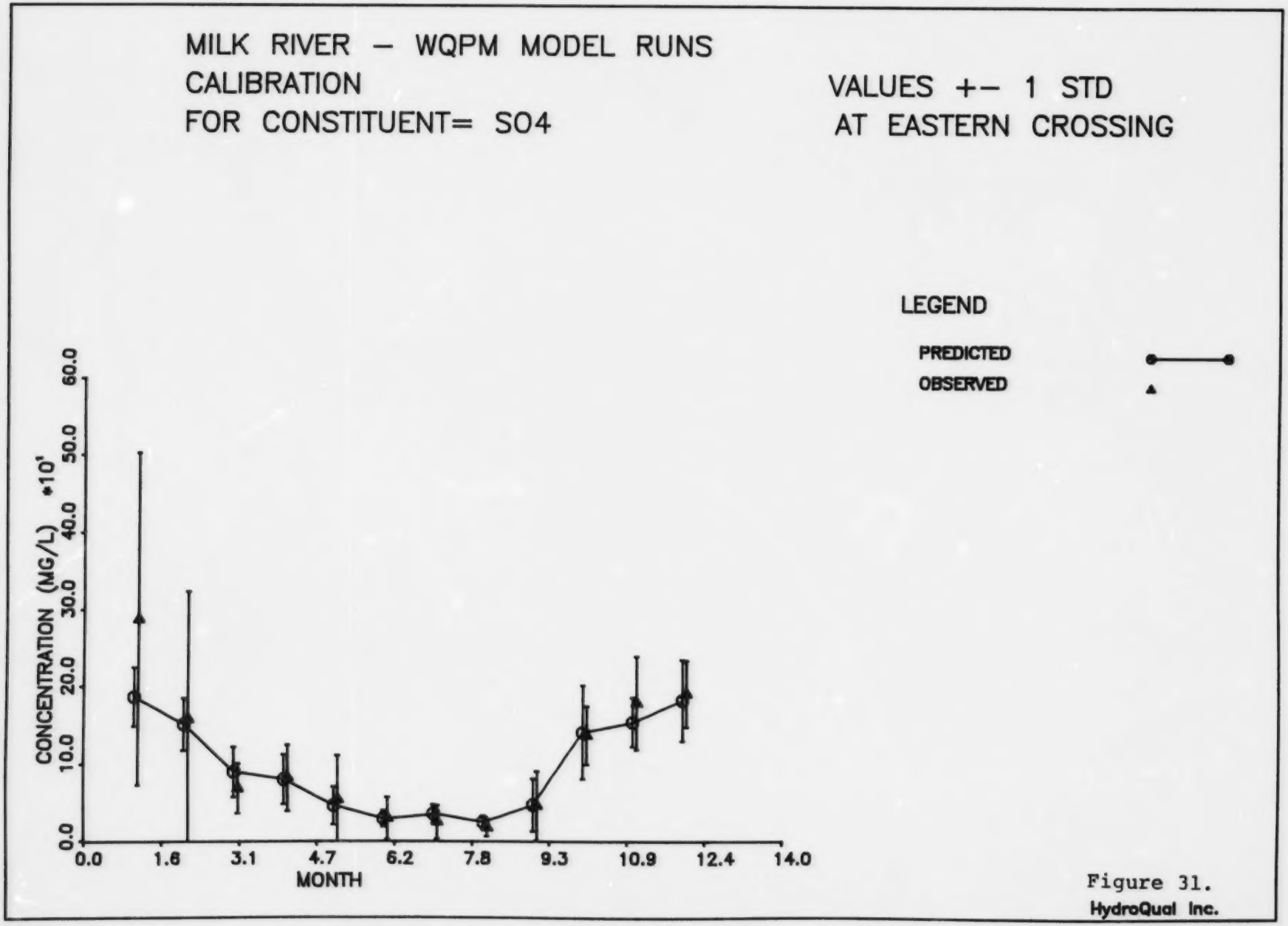


Figure 31.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= SO4

VALUES +– 1 STD
AT EASTERN CROSSING

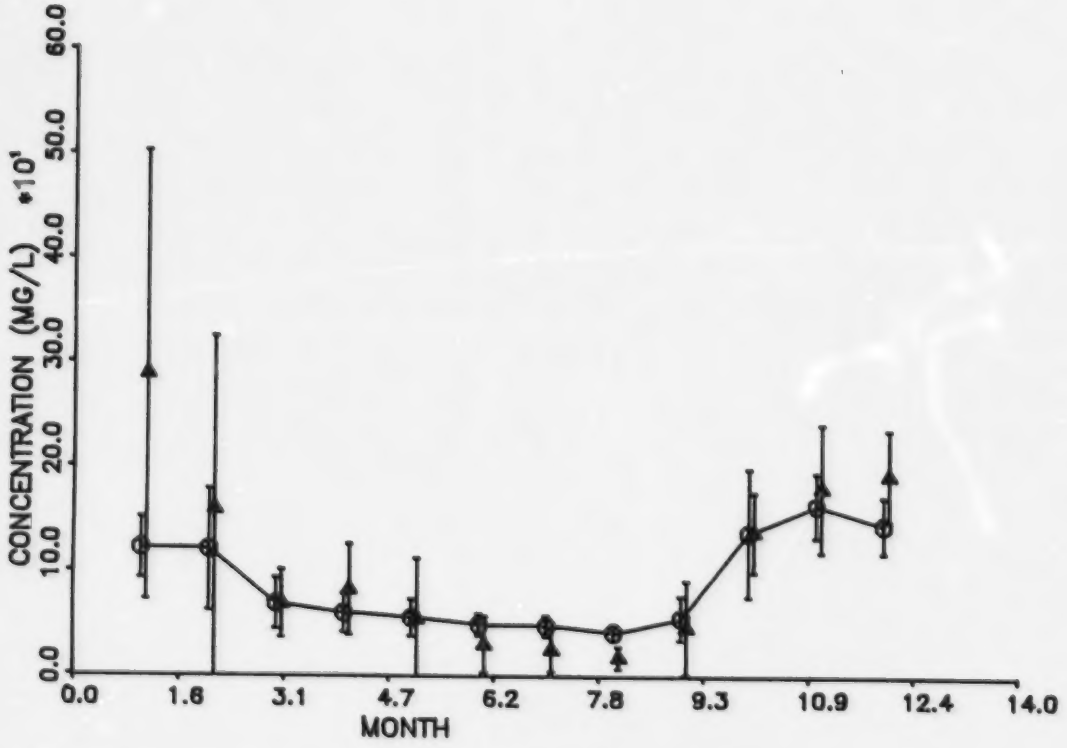


Figure 32.

HydroQual Inc.

Our predictions are based upon a simple mass balance. This is valid, since most major ions are generally considered to be conservative. However, there is a tendency for calcium carbonate to be depleted from the epilimnion of productive reservoirs. This can in turn effect downstream chemistry if withdrawals are from surface or mid-depth outlets.

3.5 NUTRIENTS & TROPHIC STATUS

Like suspended solid concentrations, the existing total phosphorus (TP) levels in the Milk River are strongly impacted by sediment resuspension and bank erosion. During calibration WQPM predicted relatively low concentrations at Milk River Town, whereas, considerable diffuse source inflows had to be included to bring levels at the Eastern Crossing up to observed levels (Figures 33 to 36). Observed river phosphorus data from 1986 (Figure 37) generally coincide with the pattern observed for NFR, however in the historical dataset total phosphorus concentrations tend to peak in June, whereas NFR peaks in April. This difference in timing is not fully understood but may be a relative function of erosional input of particulates versus dissolved phosphorus loadings from feedlot activity or livestock grazing.

Reservoir concentrations of TP are predicted to average 0.019 mg/l. This assumes a net sedimentation rate defined by the empirical relationship with areal water load which was developed for western reservoirs by Mueller (1982). In Table 5 we adjusted the most probable sedimentation rate by plus and minus 25% to assess the sensitivity of this parameter. These adjustments caused the predicted long-term average TP concentration to vary from 0.016 mg/l to 0.023 mg/l. In summary, it seems probable that the proposed reservoir will have an average phosphorus concentration near 0.020 mg/l.

Our predictions assume complete mixing, whereas in reality concentrations may vary along the length of the reservoir. Particulate phosphorus input as erosional loading from the North Milk channel may cause higher relative TP concentrations near the inlet. Sedimentation may then

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= TP

VALUES +– 1 STD
AT MILK RIVER TOWN

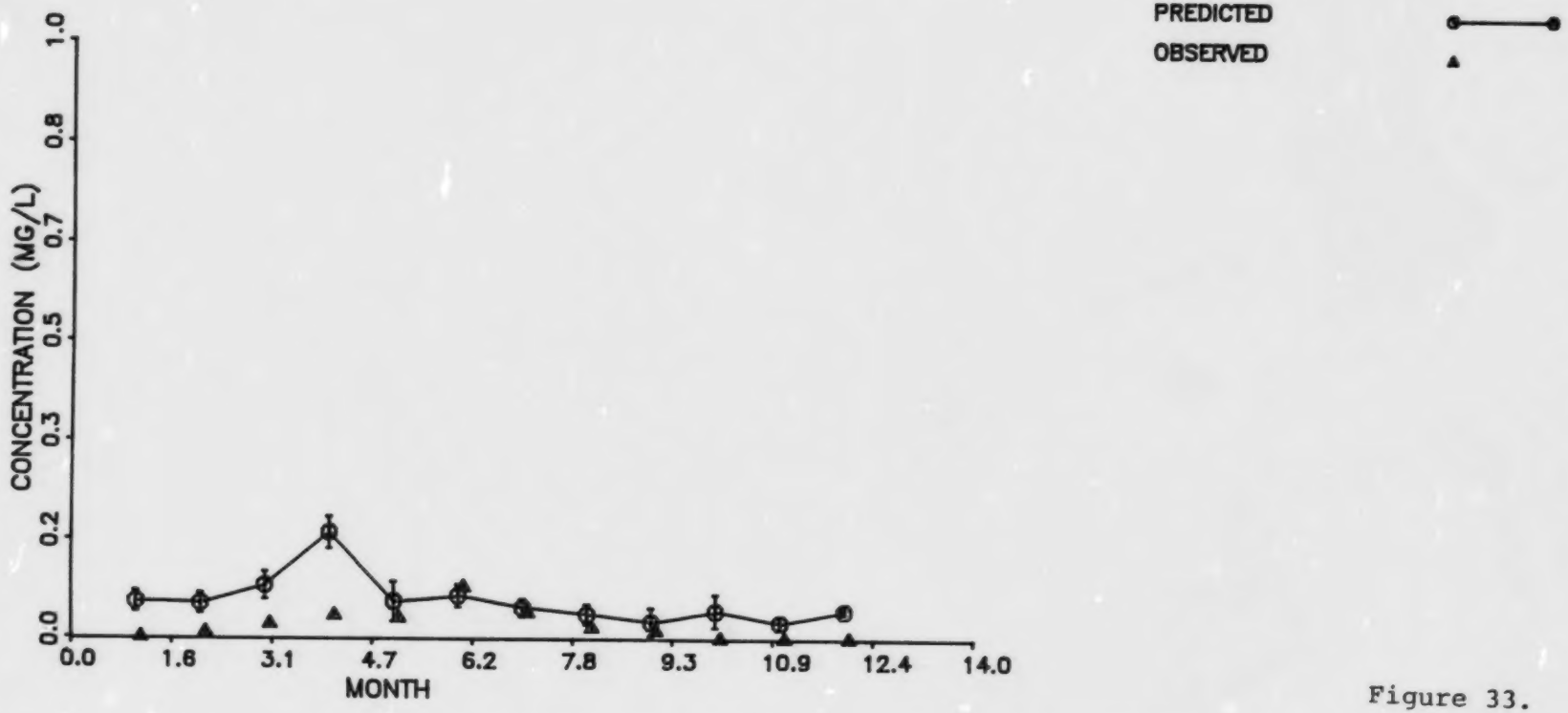


Figure 33.
HydroQual Inc.

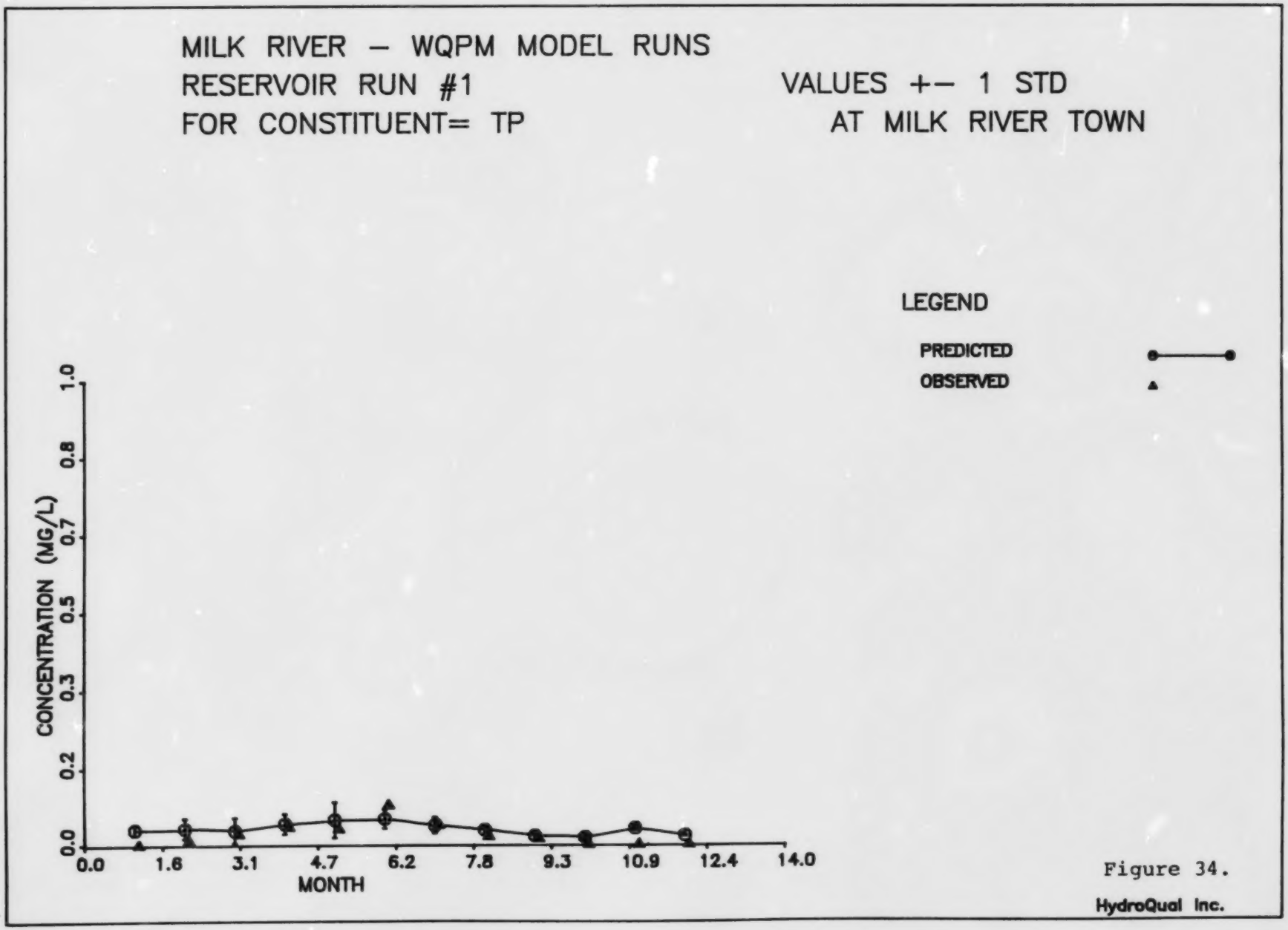

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= TP
VALUES +– 1 STD
AT MILK RIVER TOWN
LEGEND
PREDICTED
OBSERVED
CONCENTRATION (MG/L)
0.0
0.2
0.3
0.5
0.7
0.8
1.0
0.0
1.6
3.1
4.7
6.2
7.8
9.3
10.9
12.4
14.0
MONTH
HydroQual Inc.

Figure 34.

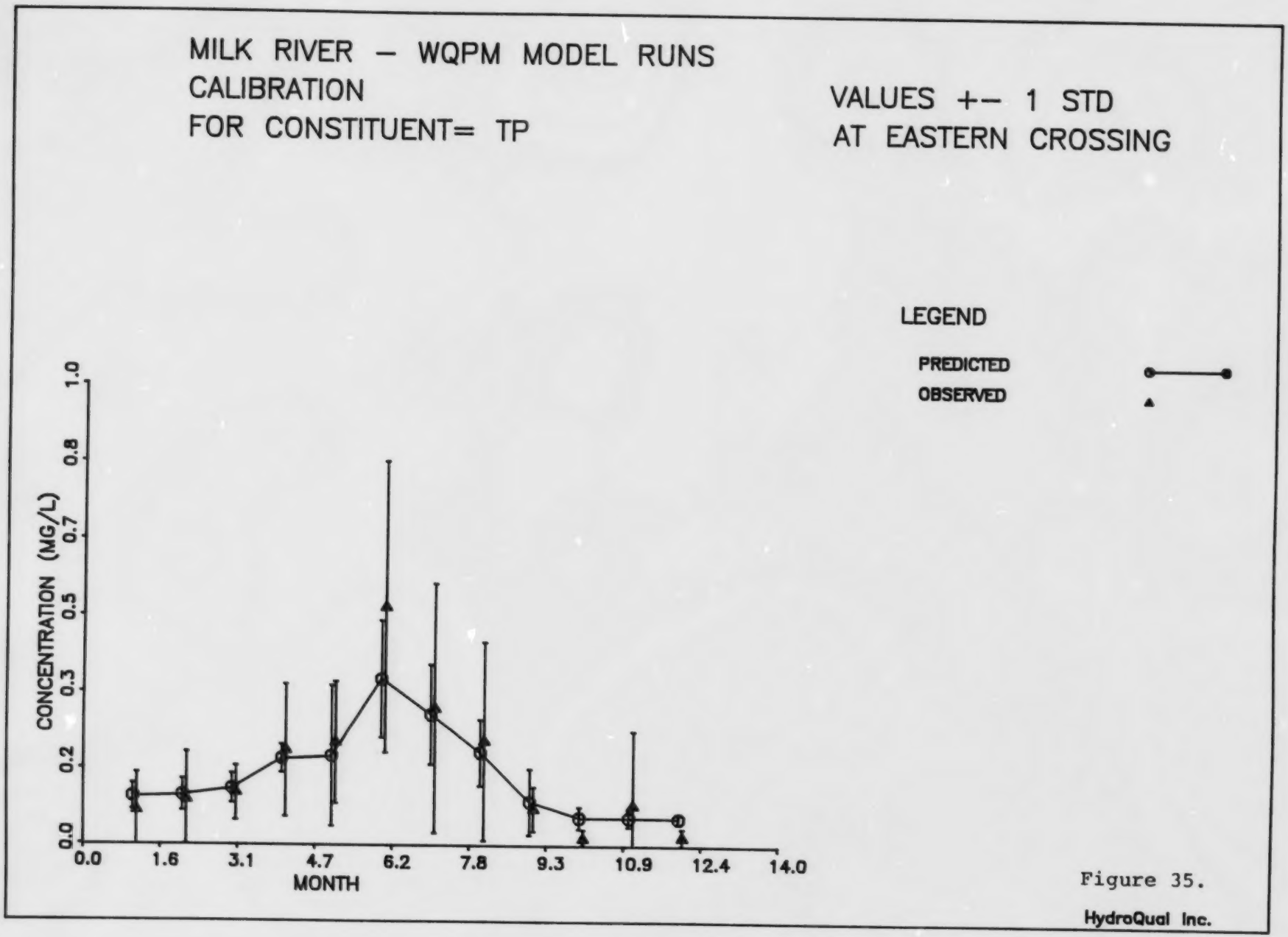


Figure 35.

HydroQual Inc.

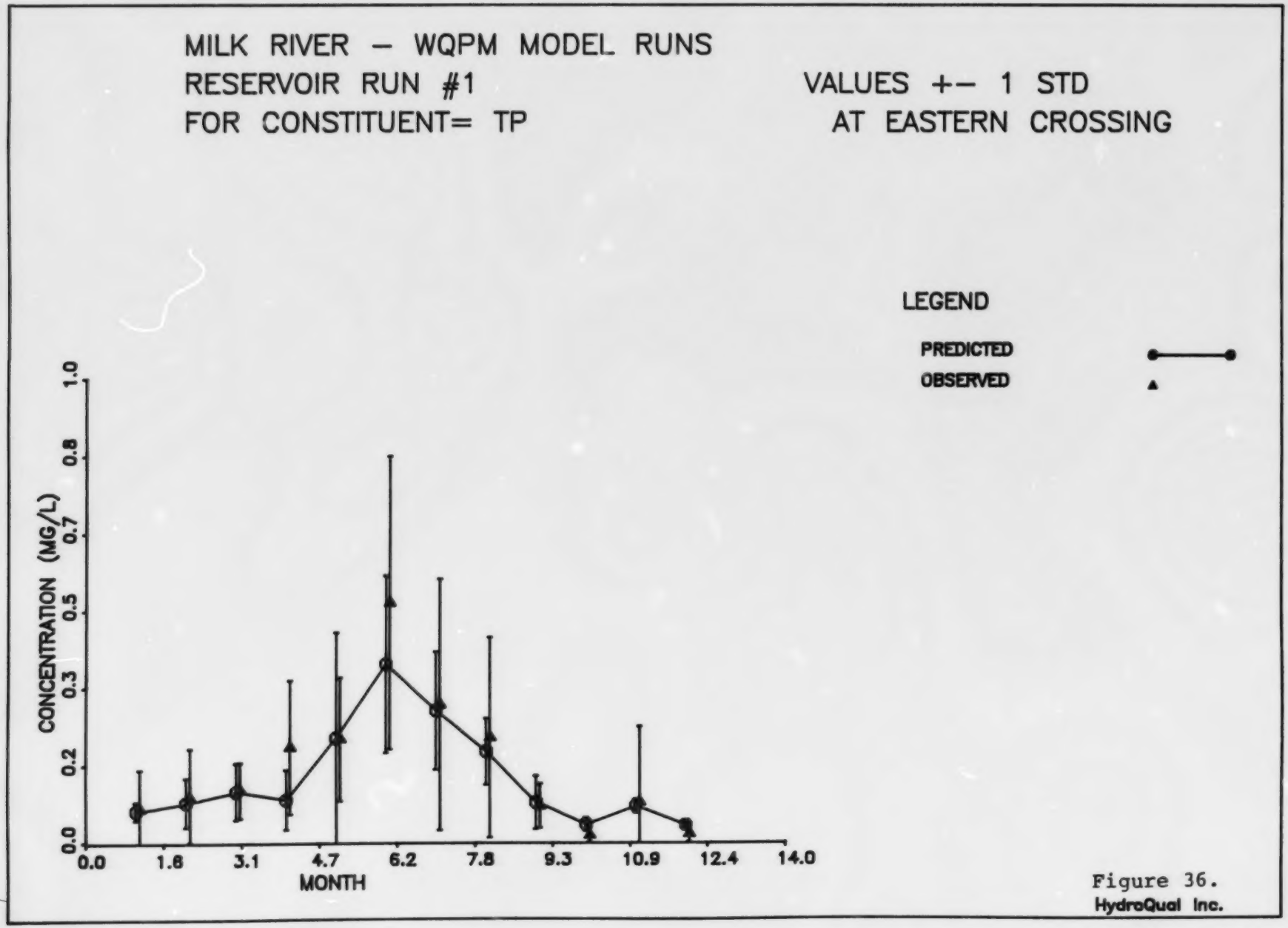


Figure 36.
HydroQual Inc.

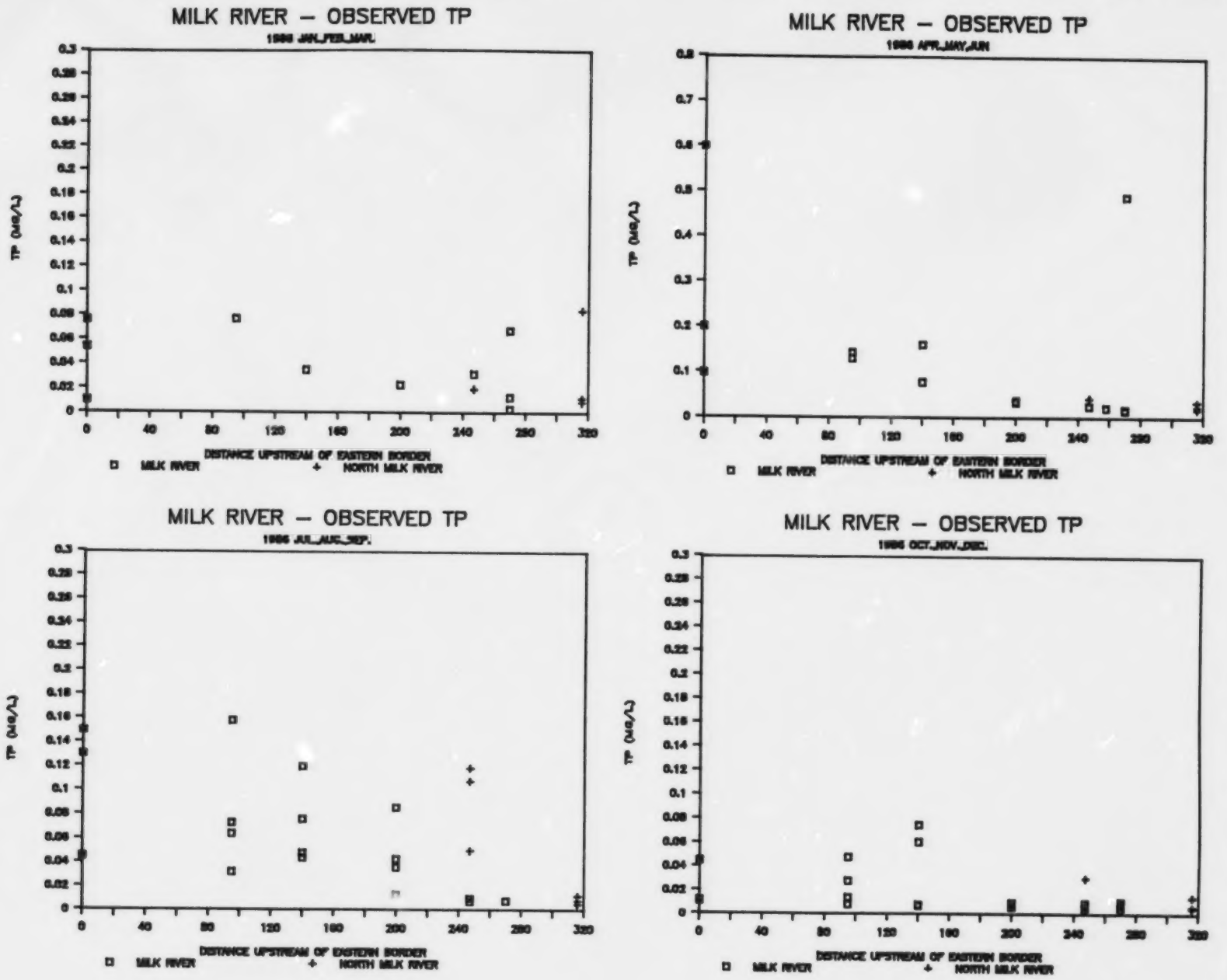

MILK RIVER – OBSERVED TP
1986 JAN,FEB,MAR.
TP (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER
MILK RIVER – OBSERVED TP
1986 APR,MAY,JUN
TP (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER
MILK RIVER – OBSERVED TP
1986 JUL,AUG,SEP.
TP (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER
MILK RIVER – OBSERVED TP
1986 OCT,NOV,DEC.
TP (MG/L)
DISTANCE UPSTREAM OF EASTERN BORDER
MILK RIVER
NORTH MILK RIVER

Figure 37.

Table 5. Sensitivity analysis on prediction of average total phosphorus concentration for WRMM RUN #1. Units are mg/l. Standard deviation indicated in brackets.

	IP	
Most probable retention	0.019	(0.011)
Retention increased by 25%	0.023	(0.011)
Retention decreased by 25%	0.016	(0.011)

result in lower concentrations closer to the dam and along the arm extending up the Milk River Valley (Chapra, 1981), creating a slight trophic gradient along the length the reservoir. We assume this gradient will be small because 1) the erosional loading is not substantial and 2) much of this eroded material may be biologically non-available (Cross et al, 1986).

It is forecast that total phosphorus concentrations in the Milk River at Milk River town will be reduced slightly from the existing condition. At eastern crossing the TP levels should remain largely unchanged because diffuse source inputs along the lower reach will remain the same.

Existing inorganic phosphorus concentrations in the Milk River can be reduced by biological uptake in the reservoir, especially if there is a surface or mid-depth withdrawal. In stratified and productive reservoirs, soluble reactive phosphorus can accumulate in the bottom waters and be released from a deep outlet. This can create nutrient enrichment problems in the downstream channel.

Although we have predicted average ammonia and nitrate +nitrite concentrations these values must be considered very approximate (Figures 38 to 45). Inorganic nitrogen concentrations can be drastically altered by reservoir processes which, other than dilution, have not been considered here. In moderately productive systems inorganic nitrogen concentrations are usually biologically converted to organic nitrogen processes during the active growing season (Petts 1984). During winter, ammonia concentrations can increase due to bacterial decay of the organic production from the previous growing season. In deep stratified reservoirs ammonia can accumulate in the hypolimnion during summer, and if it is released from a bottom withdrawal can accentuate downstream concentrations. Our simulations indicate the normal seasonal pattern in river ammonia and nitrate will be dampened by the reservoir. This will most probably occur, but may not be as static as the model predicts due to reservoir processes. Location of the outlet will also play a prominent role in determining nutrient conditions in the downstream river channel. A bottom withdrawal will tend to favour higher ammonia and nitrate concentrations in the downstream river channel than a mid or top withdrawal.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= NH3

VALUES +– 1 STD
AT MILK RIVER TOWN

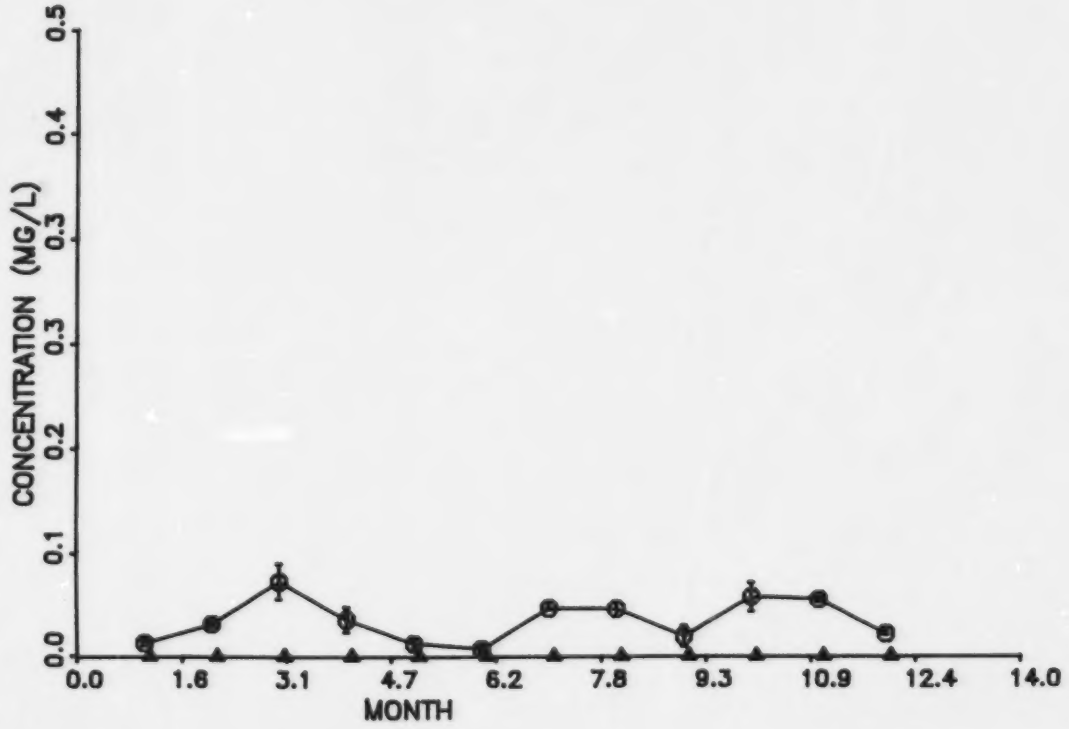


Figure 38.
HydroQual Inc.

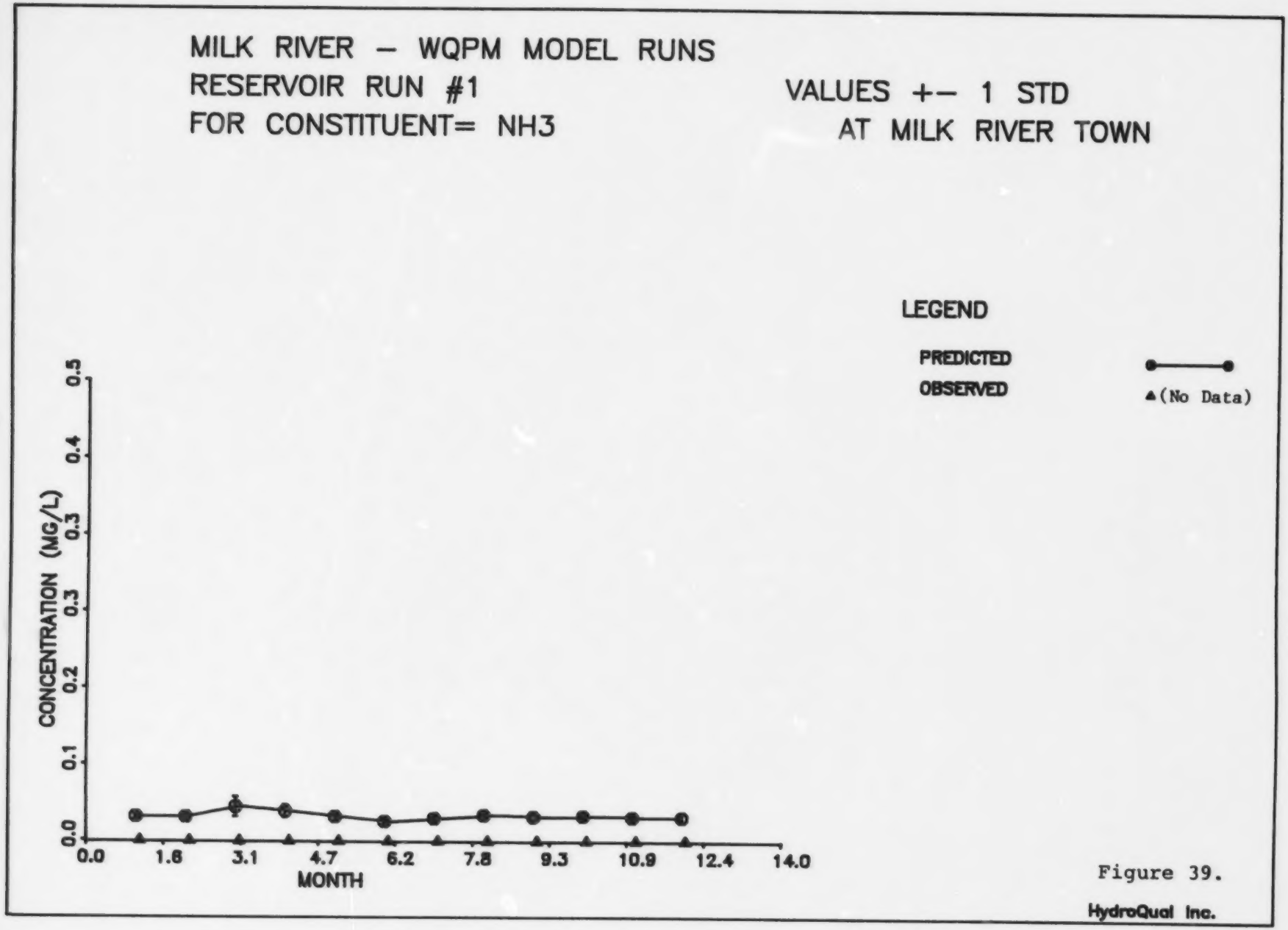


Figure 39.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
CALIBRATION
FOR CONSTITUENT= NH3

VALUES +– 1 STD
AT EASTERN CROSSING

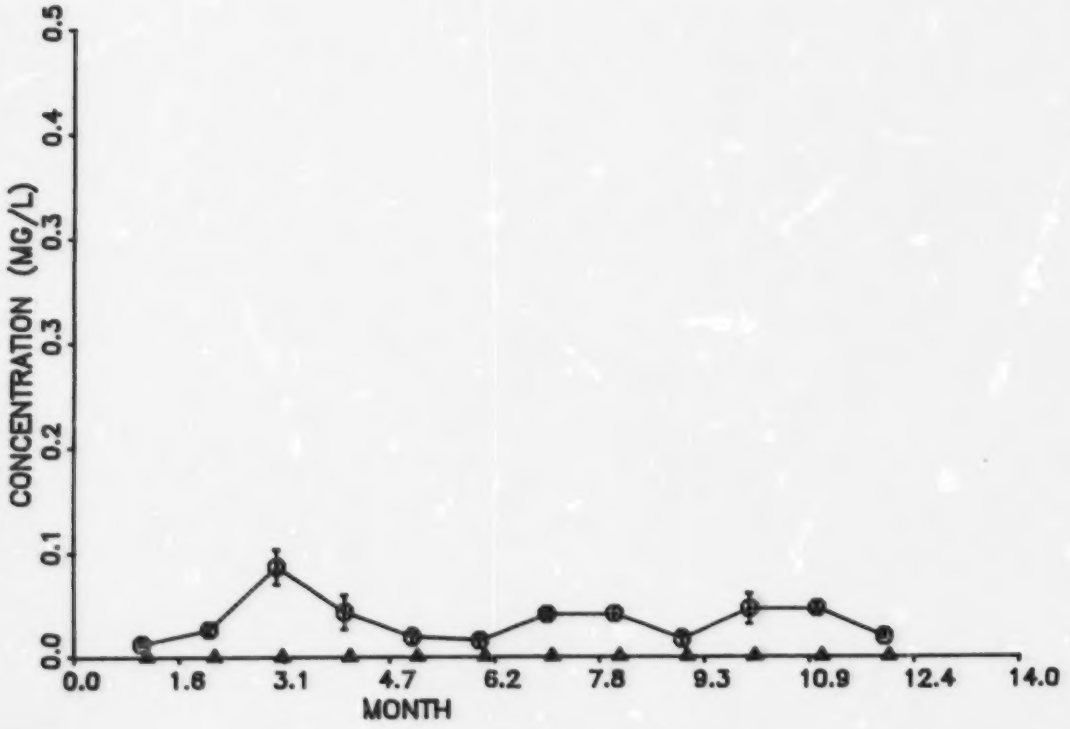


Figure 40.

HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= NH3

VALUES +– 1 STD
AT EASTERN CROSSING

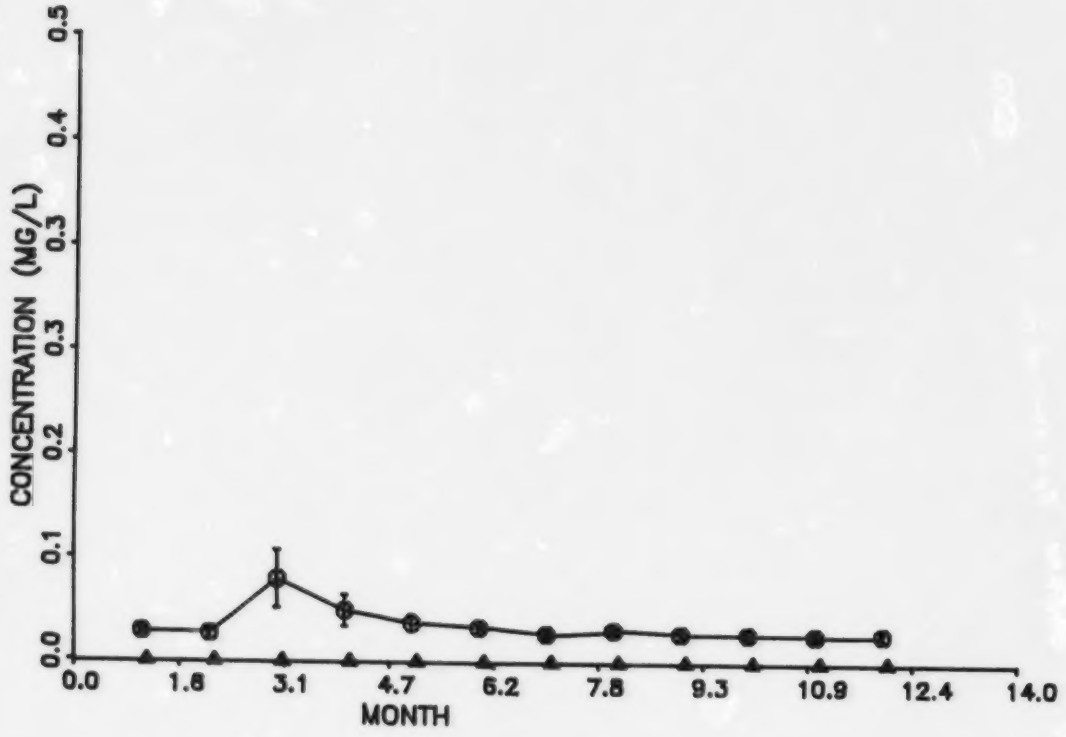


Figure 41.

HydroQual Inc.

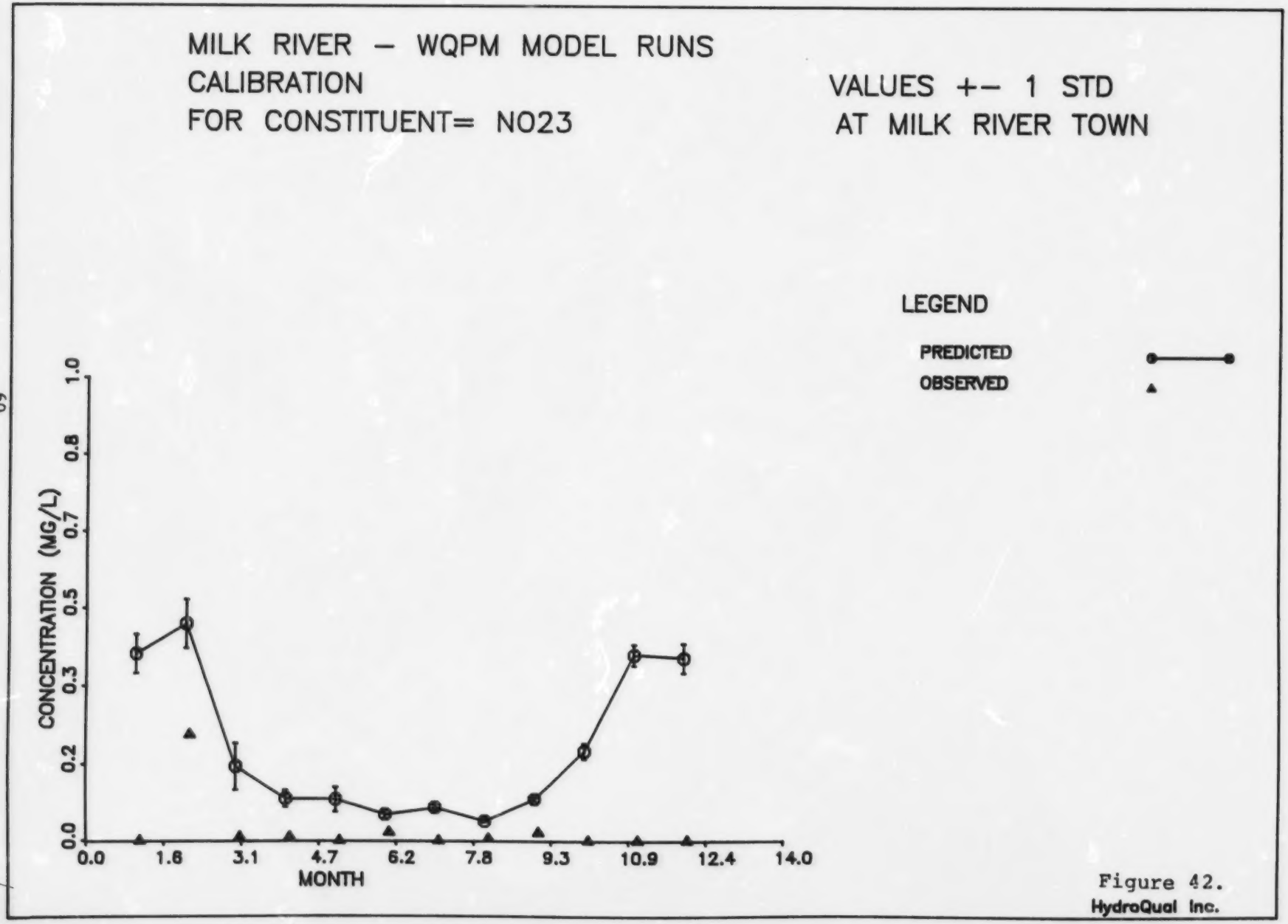


Figure 42.
HydroQual Inc.

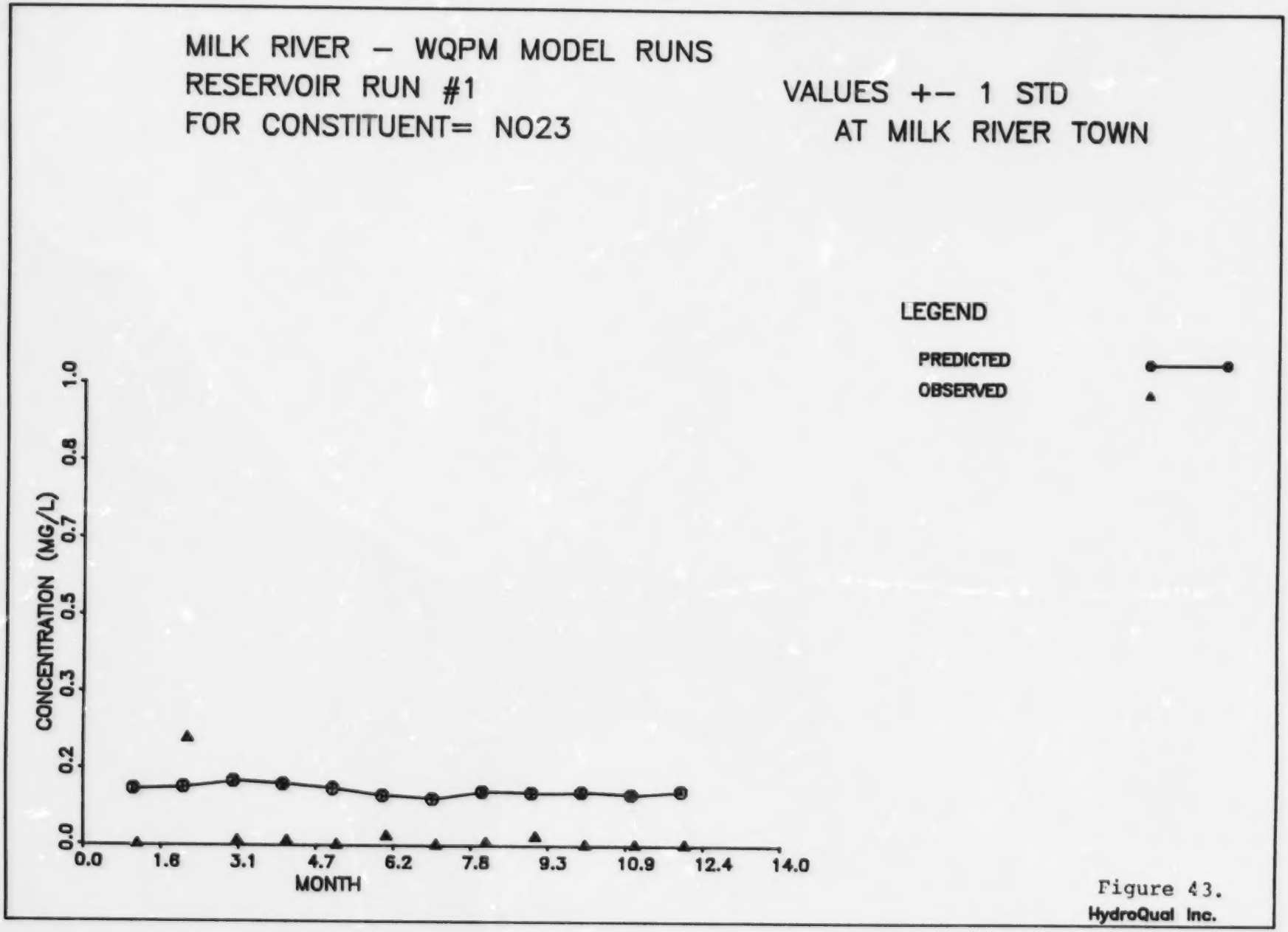


Figure 43.

HydroQual Inc.

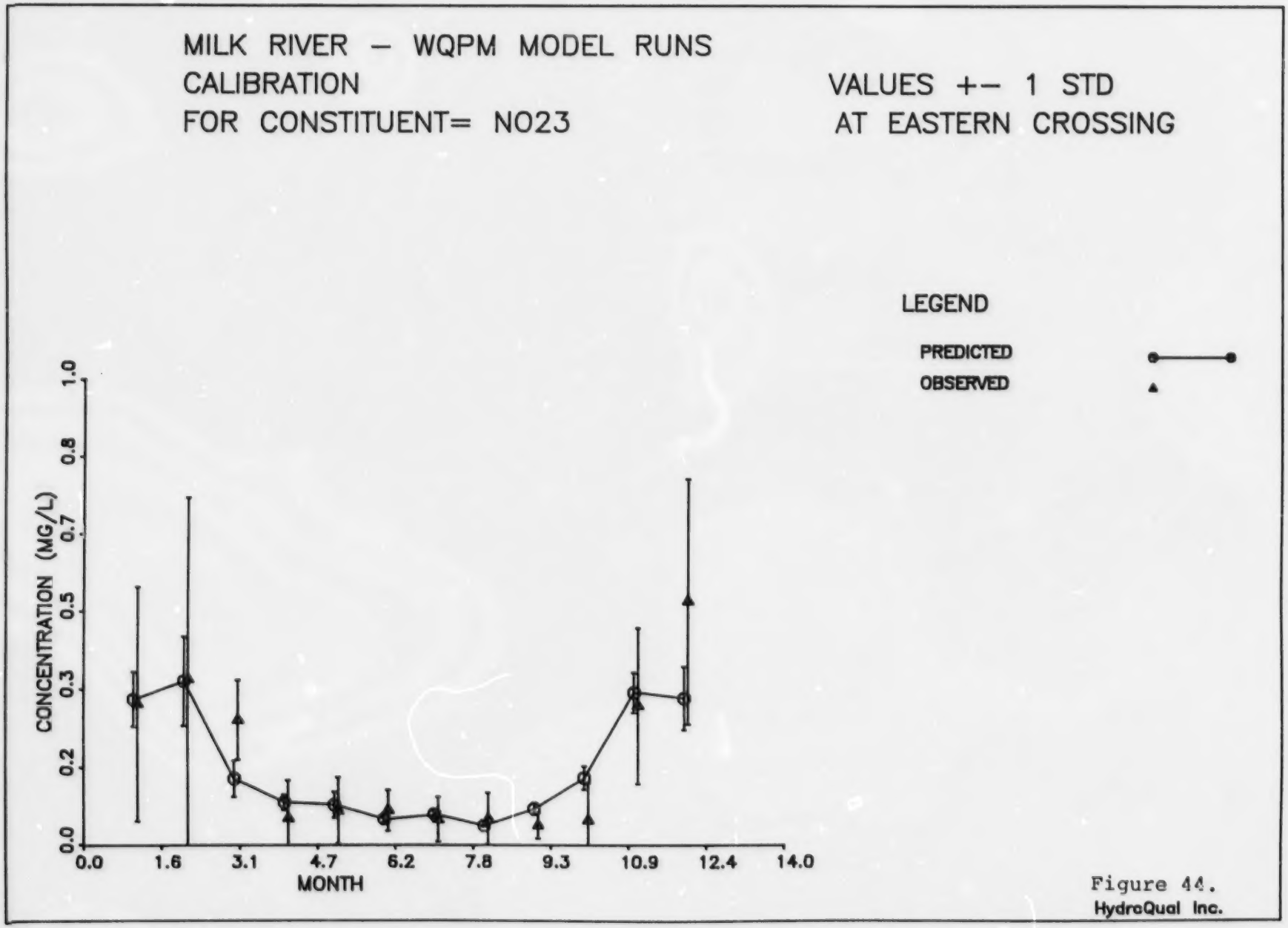


Figure 44.
HydroQual Inc.

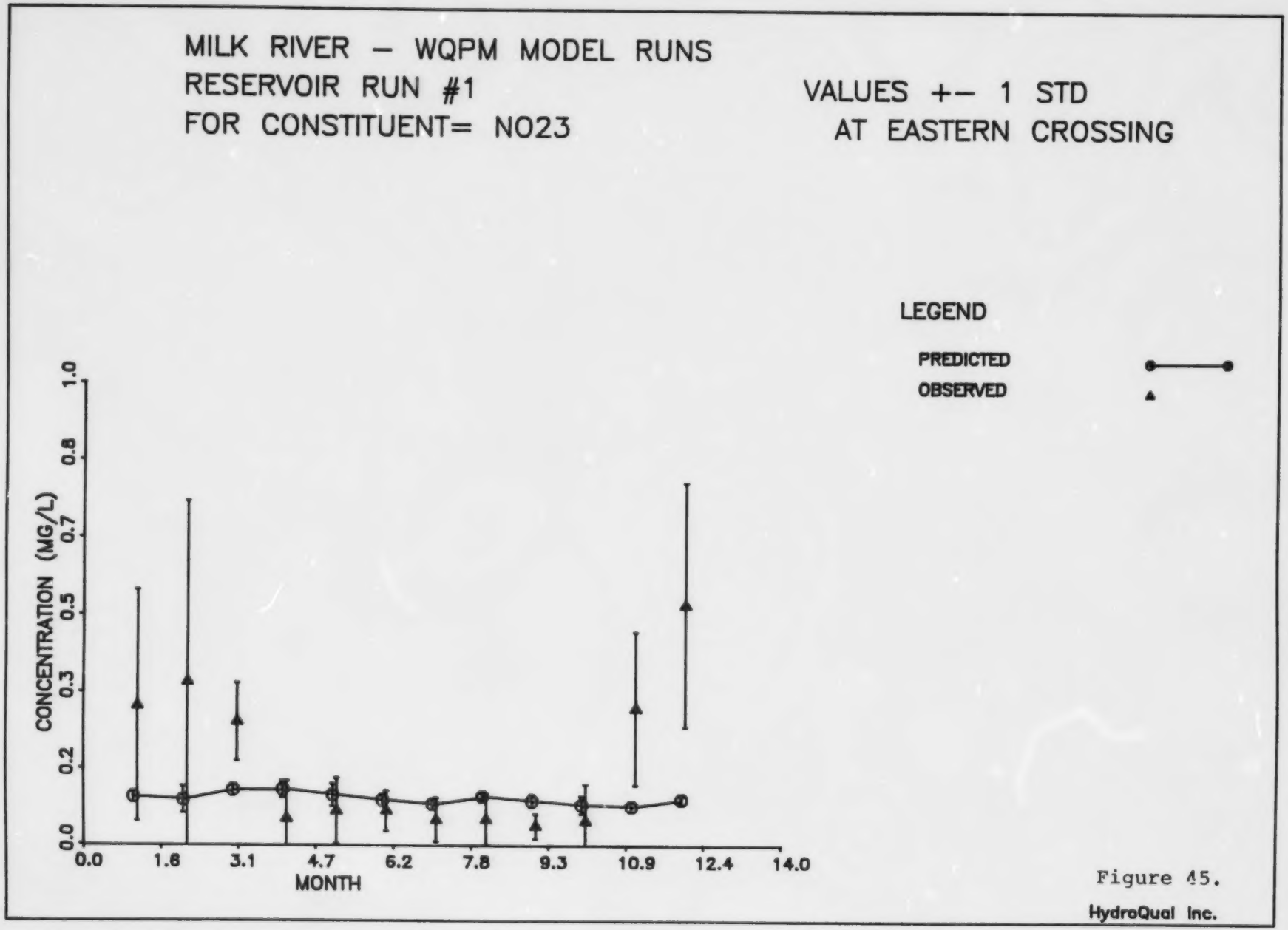

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= NO23
VALUES +– 1 STD
AT EASTERN CROSSING
LEGEND
PREDICTED
OBSERVED
CONCENTRATION (MG/L)
0.0
0.2
0.3
0.5
0.7
0.8
1.0
0.0
1.6
3.1
4.7
6.2
7.8
9.3
10.9
12.4
14.0
MONTH
HydroQual Inc.

Figure 45.

Table 6. Trophic state classification according to Mancini et al 1983.

	OLIGOTROPHIC	MESOTROPHIC	EUTROPHIC
Total Phosphorus (mg/l)	<0.010	0.010 - 0.020	>0.020
Chlorophyll (mg/l)	<4	4 - 10	>10
Secchi Depth (m)	>3.7	2 - 4	<2

Based upon the trophic state classification published by the USEPA (Mancini et al 1983) (Table 6) the proposed Milk River Reservoir will probably fall within the upper mesotrophic category. Its predicted TP concentration of 0.019 mg/l is just on the border between mesotrophic and eutrophic, whereas the predicted summer average chlorophyll of 6.4 mg/l falls well within the mesotrophic range.

The Milk River Reservoir is predicted to be slightly more productive than the Oldman and Dickson Reservoirs. This is largely a function of its lower relative flushing rate. A mesotrophic classification means it will be subject to moderate algal productivity and algal blooms on an infrequent basis.

If there is a surface or mid-depth withdrawal, inorganic nutrient concentrations in the river below the dam will remain low during the summer, thereby preventing any nuisance growth of aquatic plants and algae. A bottom withdrawal could increase soluble reactive phosphorus and ammonia levels, and stimulate algal or plant productivity. As the downstream river substrates will be gravel and cobble this could favour development of filamentous algae or diatom communities in the short term. In the long term a macrophyte (vascular plant) community could establish. Any enhanced growth should be restricted to the reaches closest to the dam, at the lower end (near eastern crossing) existing patterns in primary production should be retained.

3.6 DISSOLVED OXYGEN REGIME

Low winter oxygen concentrations have been cited as an existing constraint on the Milk River fishery (A.A. Aquatic Resources, 1986). In this section we predict average winter ice-cover, and summer hypolimnetic oxygen concentrations for the proposed reservoir at two elevations; and qualitatively consider oxygen concentrations downstream of the reservoir.

Average winter oxygen concentrations were predicted with an empirical relationship for depletion rates as defined for central Alberta lakes by Babin & Prepas (1985) (Table 7). These depletion rates tend to be higher than those defined by Mathias & Barica (1980) for unproductive lakes in

Table 7. Predicted winter average oxygen concentrations for the proposed Milk River Reservoir.

	WRMM RUN #1		WRMM RUN #4	
	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
Depletion Rate ($g/m^2/day$)	0.679	0.234	0.603	0.209
Predicted Oxygen (mg/l)				
December 1	13.0	13.0	13.0	13.0
January 1	11.4	12.4	11.3	12.4
February 1	9.8	11.8	9.6	11.8
March 1	8.4	11.3	8.1	11.3
April 1	6.8	10.7	6.7	10.7

Ontario. Unfortunately, no oxygen depletion rate model has been developed specifically for reservoirs in southern Alberta. As such, we have modelled reservoir winter oxygen using depletion rates from both the central Alberta and Ontario studies. The Babin & Prepas mean depth depletion rate is considered a maximum, while the Mathias and Barica rate is considered a minimum. Other assumptions implicit to the winter oxygen projection include:

- reservoirs are at FSL, assuming 1110 m for WRMM run 1 and 1105 m for WRMM run 4
- the lakes circulate completely in the fall and go into the ice-cover period with a saturation concentration of 13.0 mg/l
- ice cover was considered to extend from 1 December to 1 April
- the predicted values are averages for the water column, not absolute minimums

At both the maximum and minimum rates of winter oxygen depletion average concentrations in the reservoir are forecast not to fall below 5.0 mg/l. This value is the Alberta surface water quality objective for oxygen (Standards and Approvals Division 1977), and is generally designed to provide optimum protection of aquatic life. This does not mean that oxygen concentrations near the sediments will not drop below the levels indicated. One would anticipate that an oxygen gradient will occur, with minimum values at the bottom and maximum values just under the ice.

During the openwater season, wind circulation will maintain adequate oxygen concentrations in the epilimnetic surface waters. Since we have predicted that the reservoir will stratify, there is the potential that hypolimnetic oxygen concentrations could be depleted. Potential hypolimnetic oxygen depletion rates were defined from an empirical relationship based upon

average phosphorus concentration and mean depth (Cornett and Rigler 1980). As for winter oxygen, there is no regional specific model to predict summer depletion. Other assumptions implicit to the summer predictions include:

- the reservoir was assumed to be at FSL for each of WRMM runs 1 and 4
- the thermocline occurs between 12 and 15 m
- thermal stratification is continuous from 15 June to 31 August
- the reservoir oxygen content at the time of stratification was set to 11.0 mg/l. This is based upon observed data from St. Mary Reservoir (Hamilton et al, 1986).

The predicted hypolimnetic concentrations are presented in Table 8. Average concentrations go lower for WRMM run 4 (6.6 mg/l) relative to WRMM run 1 (7.5 mg/l). This reflects a lesser hypolimnetic mean depth and a greater relative sediment area to volume ratio for WRMM run 4. In both instances, hypolimnetic concentrations remain relatively high. As in the winter case there will probably be a depth gradient, with lowest oxygen concentrations occurring at the bottom.

The historical pattern in winter (January and February) oxygen concentrations for the Milk River at Eastern Crossing is presented in Figure 46. Concentrations less than 5.0 mg/l occur in 22% of instances, in only 10% of instances do values fall below 2.0 mg/l. All low values tend to be associated with river flows below 1.0 m^3. There are insufficient field data from points across the basin to ascertain patterns or trends in the rate of oxygen depletion along the channel. Oxygen data from the winter of 1986/87 have remained at relatively high levels right from Western Crossing to the Eastern boundary (A. Trimbee, pers. comm.).

Table 8. Predicted summer average hypolimnetic oxygen concentrations for proposed Milk River Reservoir.

	WRMM RUN #1	WRMM RUN #4
Depletion Rate ($mg/m^2/day$)	364	341
Predicted Oxygen (mg/l)		
June 15	11.0	11.0
July 1	10.3	10.1
July 31	8.9	8.4
August 31	7.5	6.6

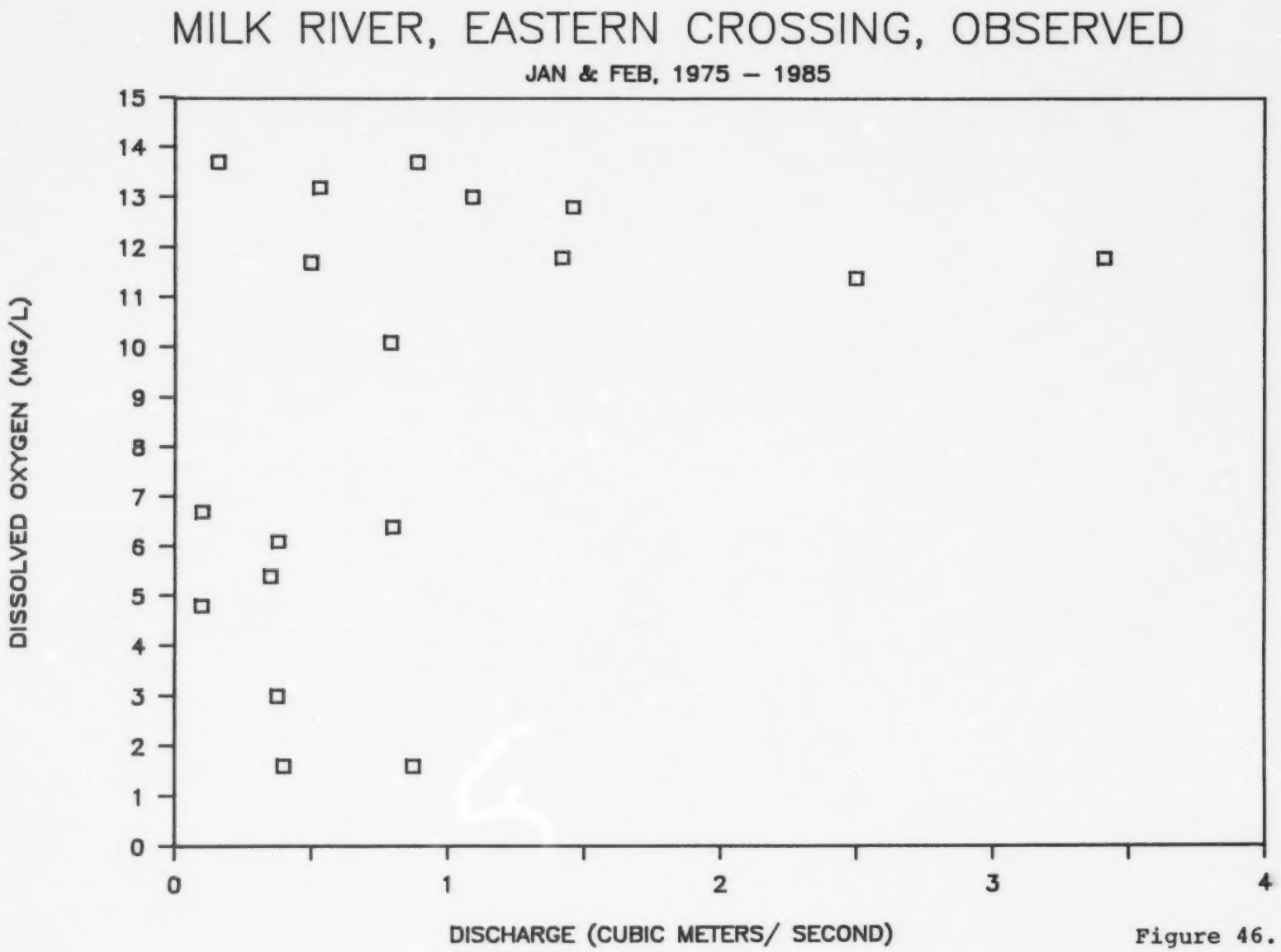

MILK RIVER, EASTERN CROSSING, OBSERVED
JAN & FEB, 1975 – 1985
DISSOLVED OXYGEN (MG/L)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
DISCHARGE (CUBIC METERS/ SECOND)

Figure 46.

With the existing database, the effect of the reservoir on downstream winter oxygen conditions cannot be carefully quantified. However, considering the fact that the winter oxygen levels in the reservoir will remain relatively high, and near saturation levels will be attained in the open water stretch below the reservoir, there is a good possibility oxygen levels at Eastern Crossing will be improved. Right now the channel appears to be biologically unproductive, and the winter depletion rate low. Assuming the depletion rates remain unaltered, the oxygen loading provided by the reservoir may be sufficient to reduce the significant winter oxygen sag at the border now occurring about 25% of the time.

3.7 OTHER ISSUES

Elevated mercury levels in fish has been a problem associated with construction of new reservoirs. In the case of the proposed Milk River reservoir, this issued is being addressed by other study components (L. Noton, Alberta Environment, pers. comm.). The historical water quality overview (A.A. Aquatic Research 1986) cited occasional high values for some other metals in the Milk River at eastern crossing. These occurrences are most probably associated with the seasonally high suspended sediment regime. This pattern is not forecast to change substantially following reservoir construction.

Indicator bacteria densities along the lower Milk River occasionally exceed recreational guideline levels (A.A. Aquatic Research 1986). These result from diffuse runoff loads from agricultural runoff and feedlots. The reservoir will not affect these impacts and therefore the seasonal high values should remain. As there are no municipal discharges upstream of the dam, bacteriological quality of the reservoir should be excellent. Localized impacts may be experienced in nearshore areas due to livestock watering.

It is beyond the scope of this study to consider trophic upsurge in detail. The upsurge period on the Dickson Reservoir was short in duration and minor in magnitude (P. Mitchell, pers. comm.), and similar

conditions are forecast for the Oldman Reservoir. Considering the similarities between the Oldman and Milk reservoirs, in terms of geographic location and depth profiles, the comparative nutrient loadings from flooded soils should be similar. However, the Milk River reservoir has a reduced flushing rate which may help to prolong the upsurge period.

4.0 CONCLUSIONS

1. With regulation, river flows downstream of the proposed Milk River reservoir will not be substantially altered from the historical condition. March, April and May flows will be slightly reduced, while summer flows will increase marginally.

2. The differences in downstream river flows for WRMM runs 1 and 4 are minor.

3. The proposed reservoir should thermally stratify during summer months. The extent and duration of the stratification interval will depend upon the flushing rate and the location of the outlet.

4. Immediately below the reservoir summer maximum water temperatures will be reduced, and winter minimum temperatures increased. The seasonal maxima and winter minima will be delayed in timing relative to the existing condition. An ice-free reach will be maintained downstream of the reservoir.

5. The existing suspended solids (turbidity) regime of the Milk River at eastern crossing should not change drastically. Water clarity will be improved immediately below the dam.

6. Headwater inflows should not create substantial reservoir turbidity. Bank slumping and wind-induced shoreline erosion will impact turbidity levels in the reservoir immediately following storms.

7. Total salinity and major ion levels in the reservoir will remain at moderate levels, well within published guidelines for irrigation and other water uses.

8. Downstream of the reservoir, summer major ion concentrations will be increased marginally, while winter high values will be reduced. The winter ion reductions will be greatest immediately below the dam and relatively less at eastern crossing.

9. Much of the existing high total phosphorus concentrations in the lower Milk River are the result of diffuse source inflows, probably associated with bank slumping and channel re-suspension.

10. Reservoir total phosphorus concentrations should average 0.020 mg/l. This level is slightly higher than observed values for the Dickson Reservoir and predicted values for the Oldman Reservoir.

11. On the trophic scale, the reservoir should fall within the upper mesotrophic range. This means it will experience moderate biological productivity. There could be a slight west-to-east trophic gradient along the reservoir.

12. Total phosphorus concentrations should be slightly reduced immediately downstream of the reservoir, but will remain largely unchanged at eastern crossing. Inorganic phosphorus levels below the dam will depend upon the location of the outlet.

13. Inorganic nitrogen levels downstream of the reservoir will also depend upon outlet location.

14. A bottom withdrawal will favour the enhanced growth of aquatic plants and algae in the reach immediately below the dam. A surface or mid-depth withdrawal will favour the existing condition. In either case, conditions at eastern crossing should remain largely unaltered.

15. At both elevations (WRMM runs 1 & 4) the average winter oxygen concentrations in the reservoir are forecast not to fall below the Alberta surface water objective of 5.0 mg/l. Summer hypolimnetic oxygen concentrations should also remain at adequate levels.

16. There are insufficient historical data to precisely predict winter oxygen concentrations in the lower Milk River. At eastern crossing winter values less than 5 mg/l have been recorded in 22% of historical samples and there is potential that the reservoir could enhance winter oxygen conditions both downstream of the reservoir and at the border.

17. Bacteriological quality and trace metal levels in the lower Milk River should not be changed significantly from the existing condition.

5.0 REFERENCES

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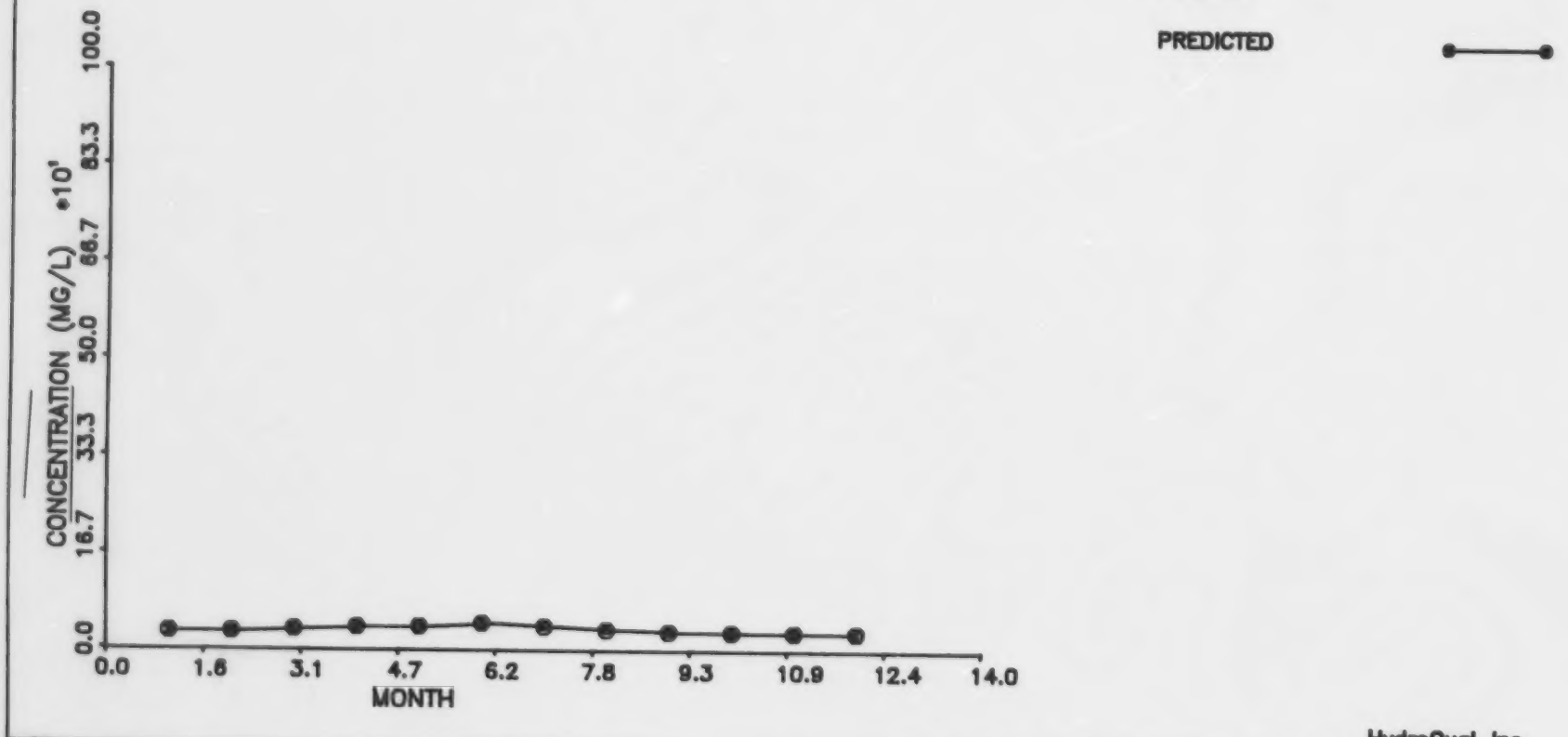
APPENDIX 1

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= NFR

VALUES +– 1 STD
AT RESERVOIR



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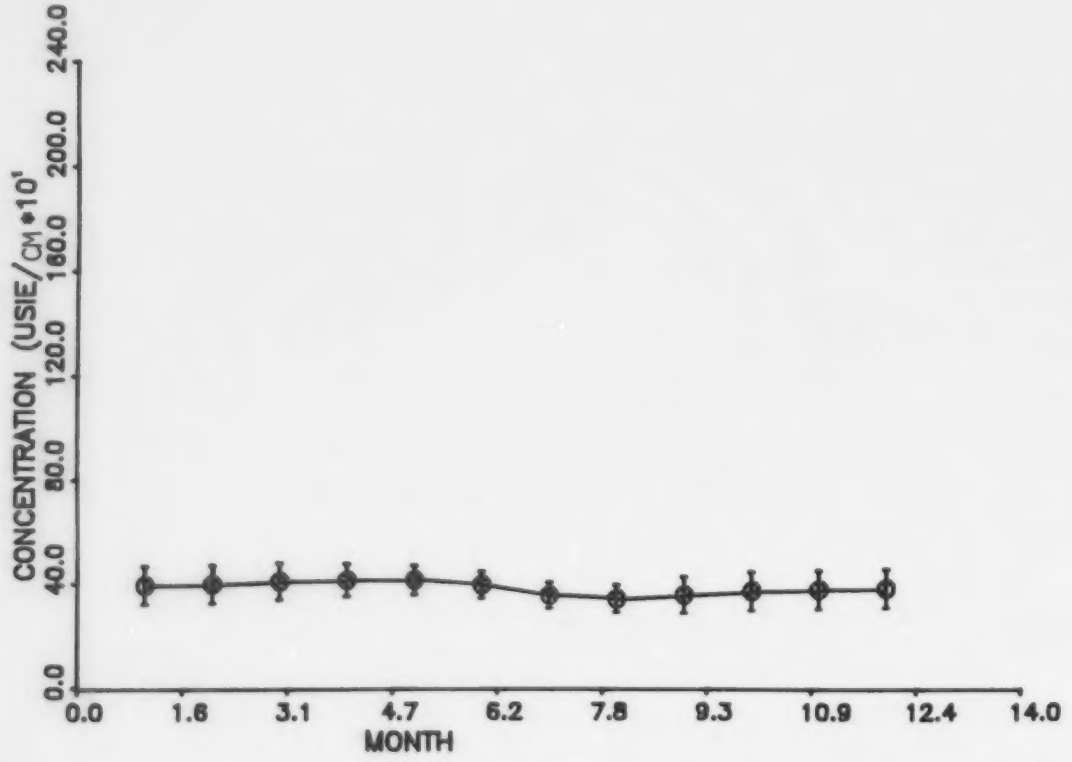
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1 VALUES +– 1 STD
FOR CONSTITUENT= CONDUCTIVITY AT RESERVOIR



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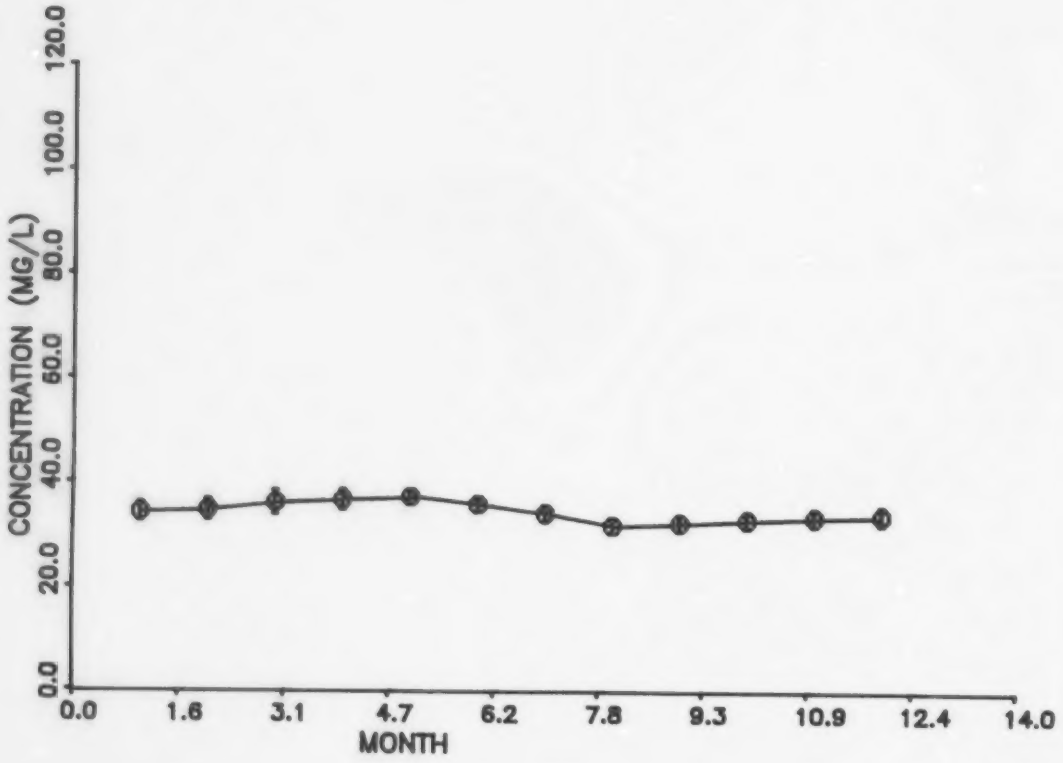
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= CALCIUM

VALUES +– 1 STD
AT RESERVOIR



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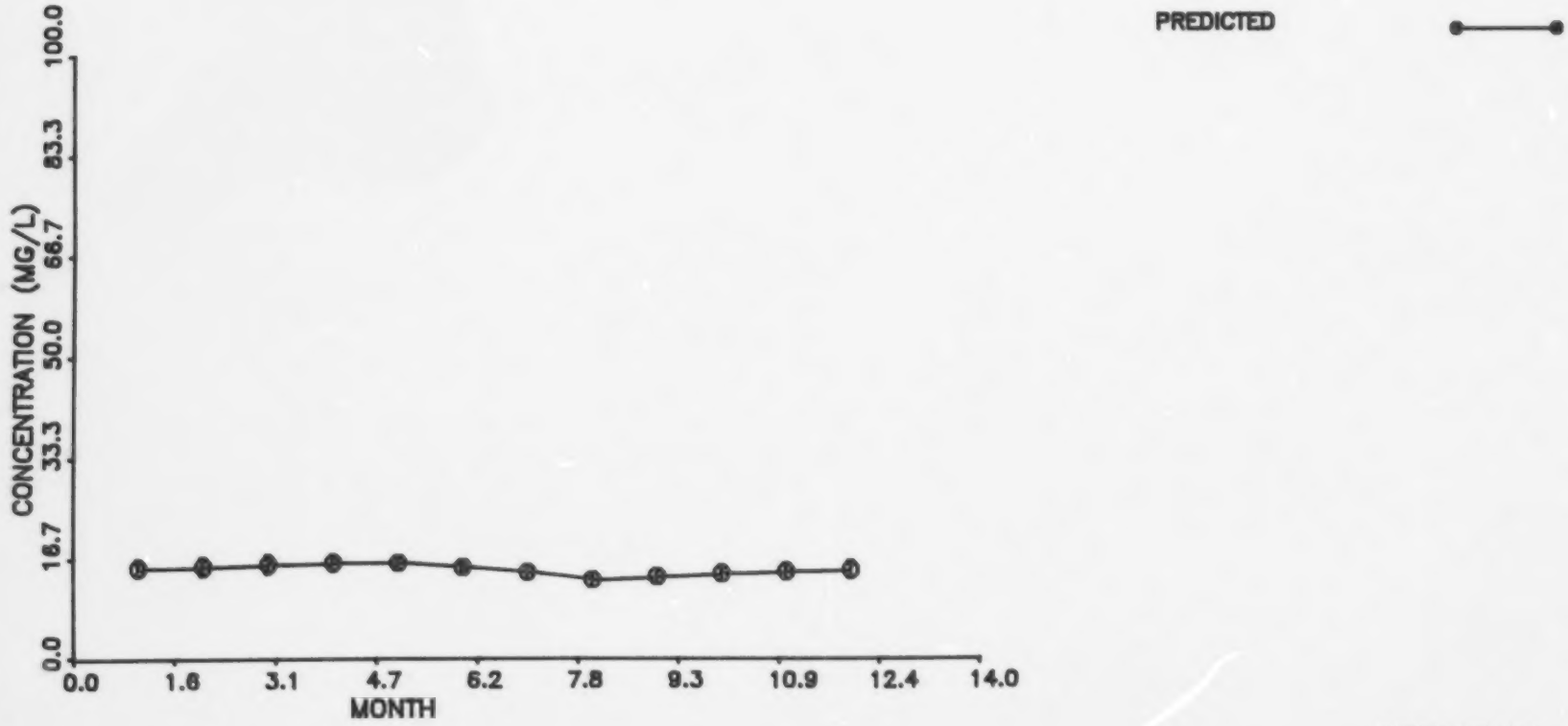
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= MAGNESIUM

VALUES +– 1 STD
AT RESERVOIR



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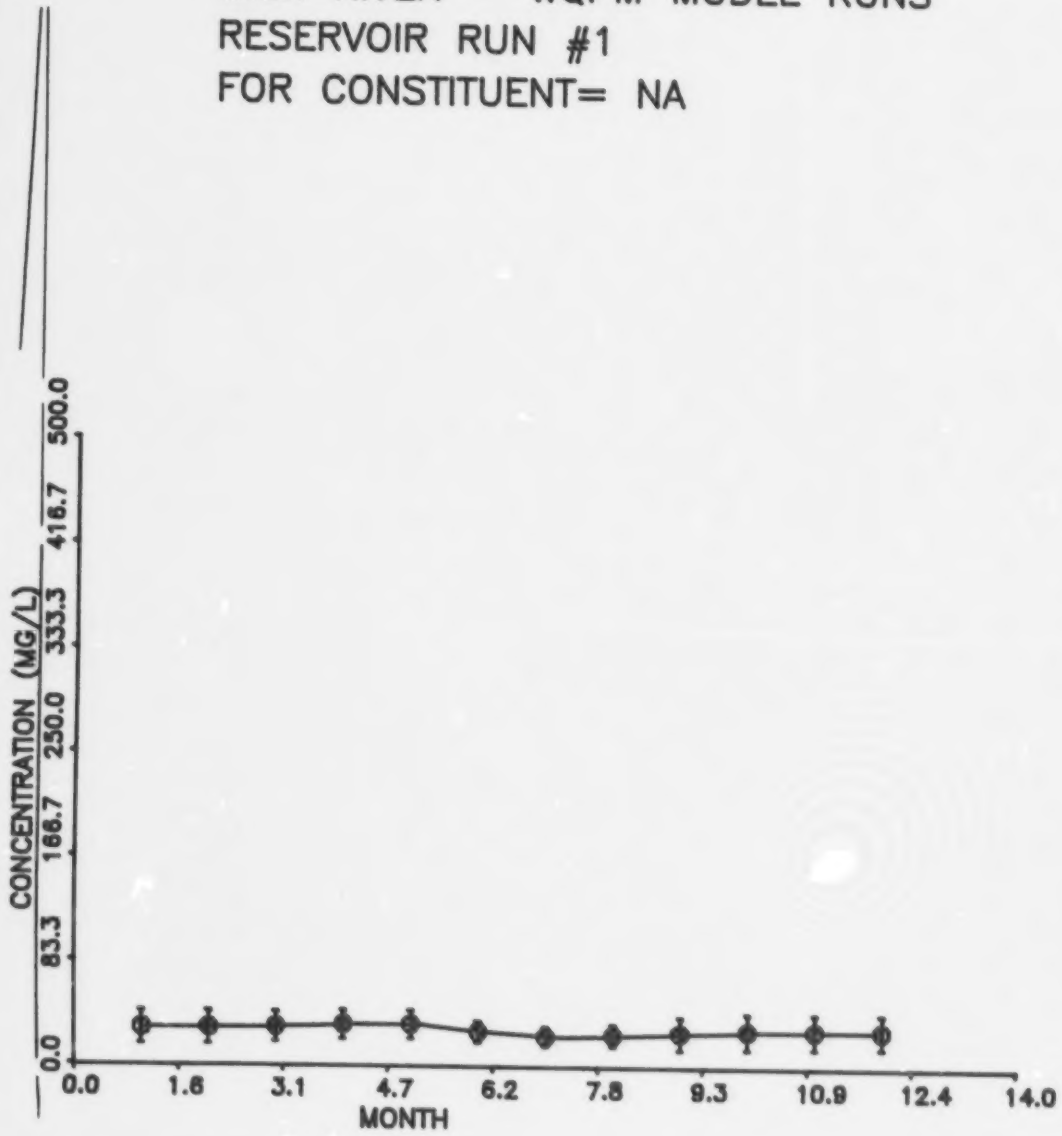
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= NA

VALUES +– 1 STD
AT RESERVOIR



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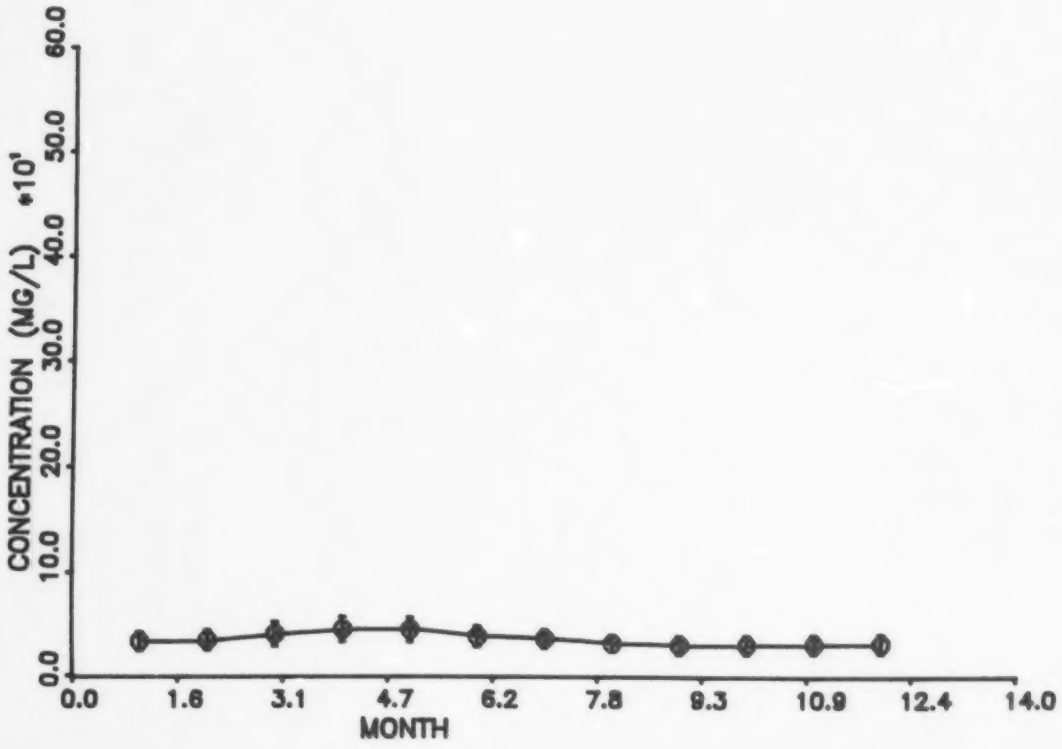
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= SO4

VALUES +– 1 STD
AT RESERVOIR



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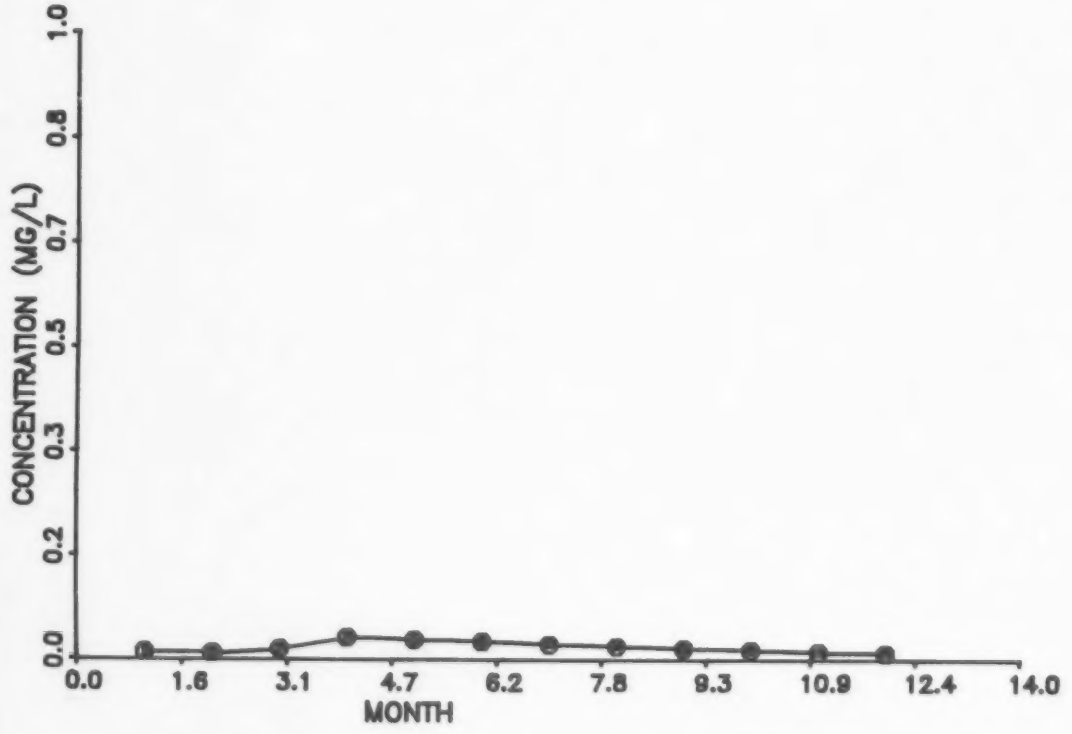
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= TP

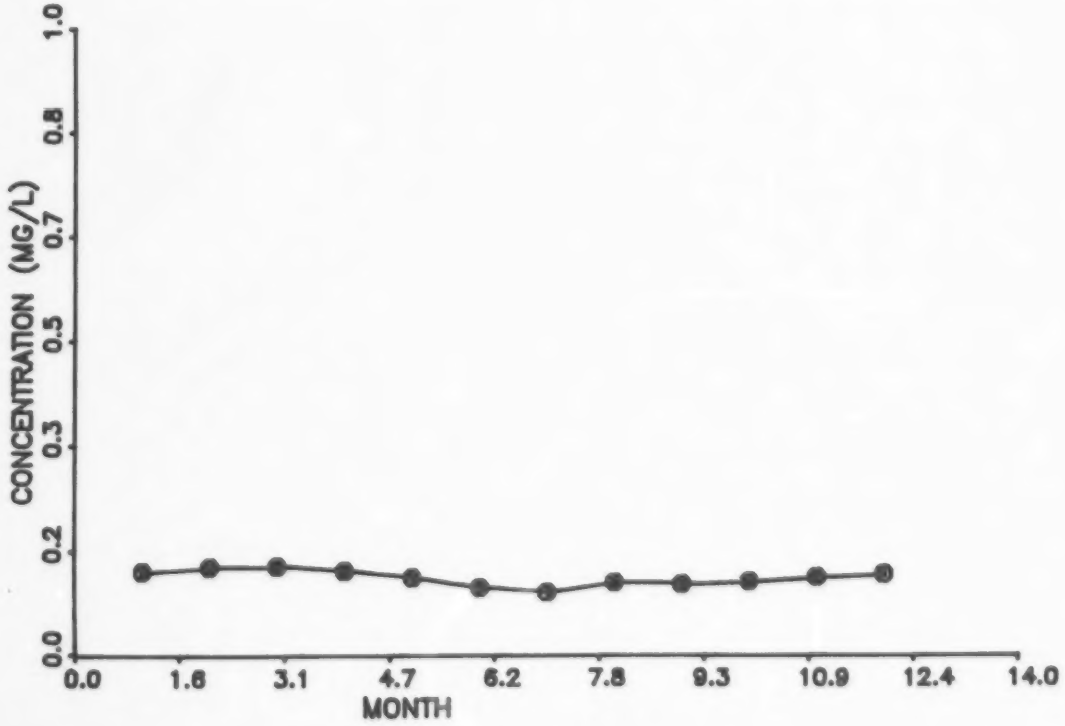
VALUES +– 1 STD
AT RESERVOIR



HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= NO23

VALUES +– 1 STD
AT RESERVOIR



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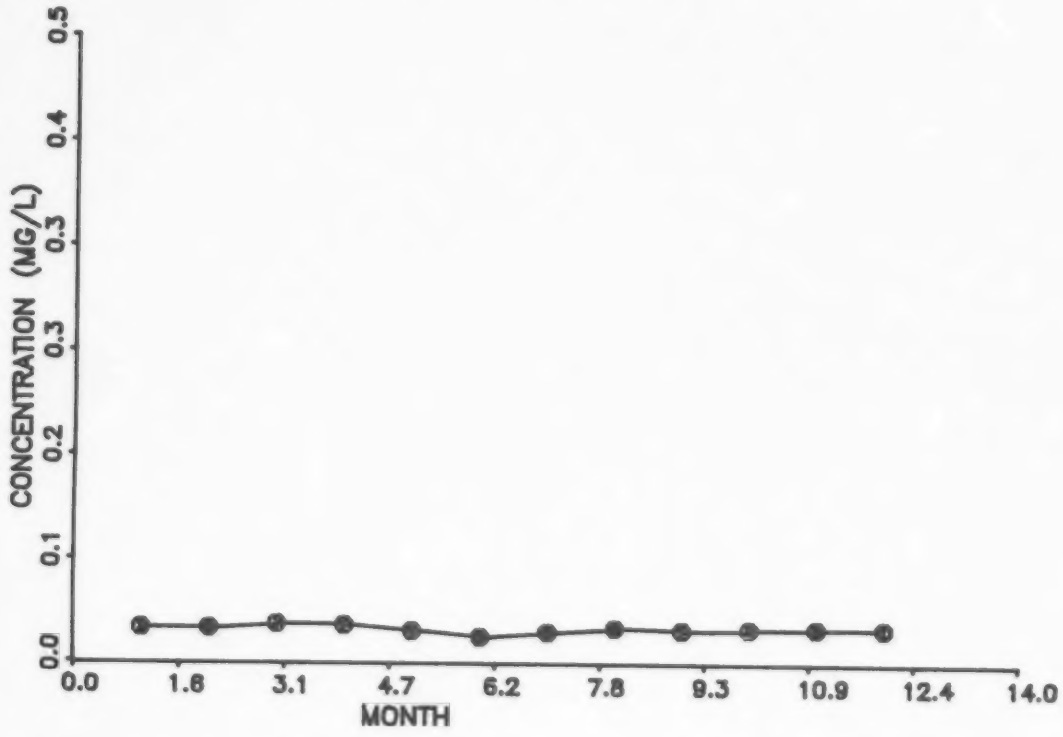
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUN #1
FOR CONSTITUENT= NH3

VALUES +– 1 STD
AT RESERVOIR



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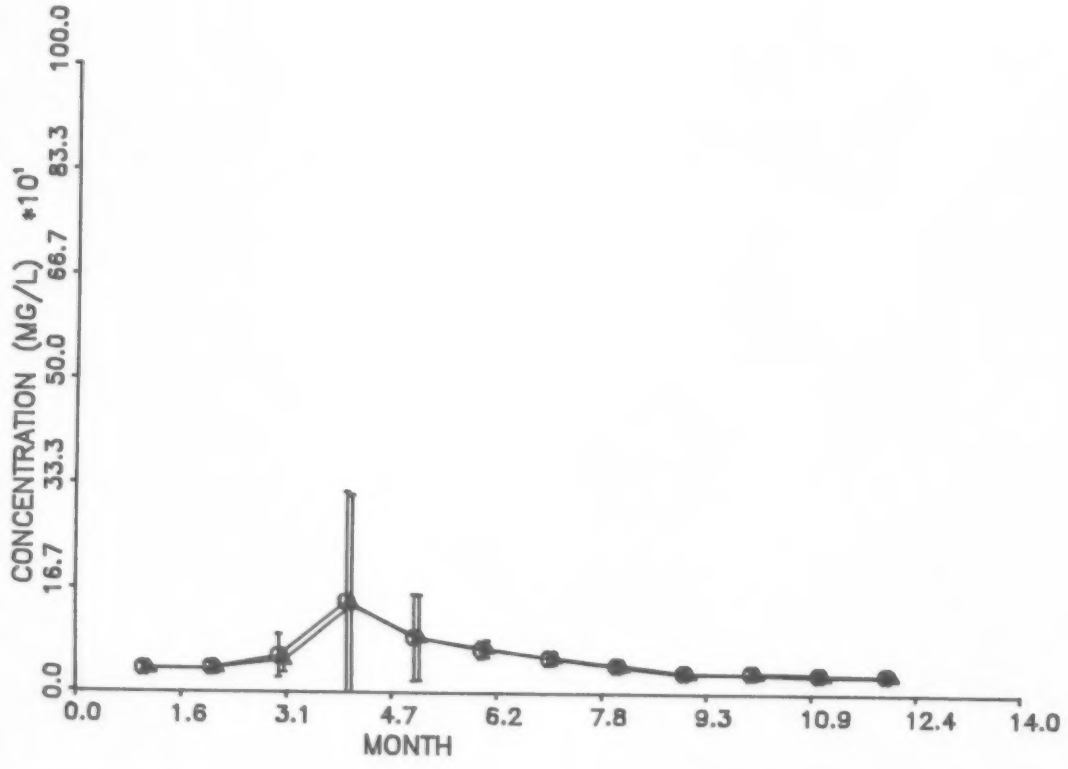
APPENDIX 2

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= NFR AT MILK RIVER TOWN



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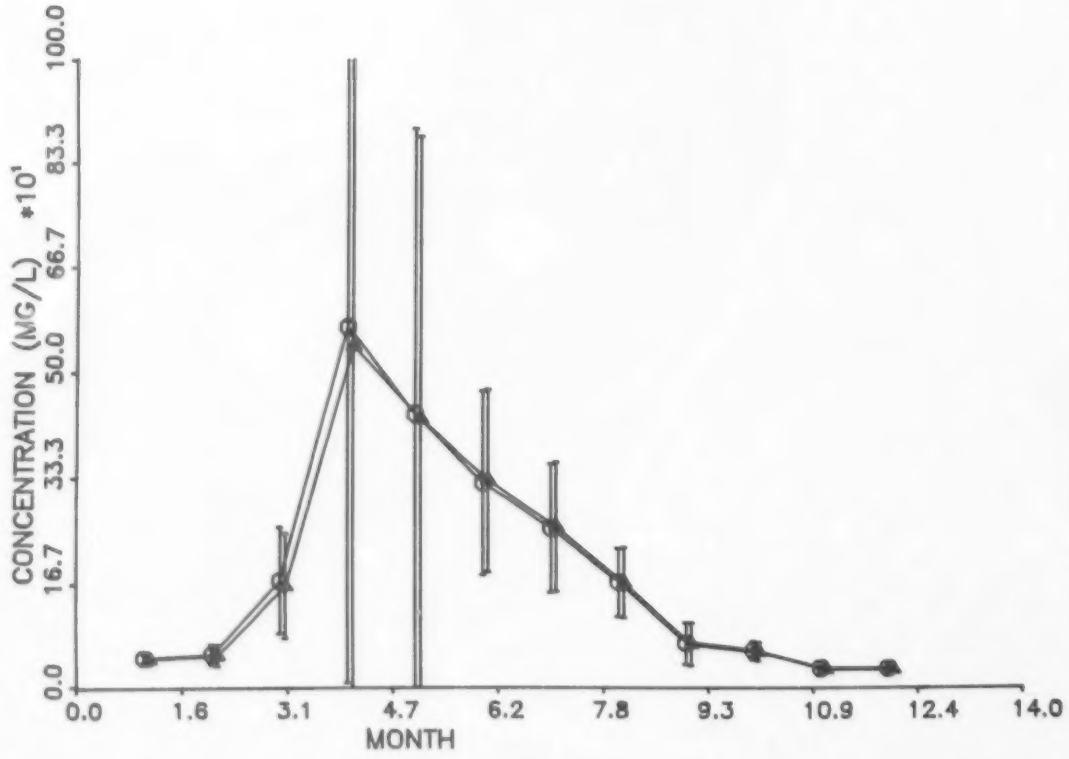
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS **#1 & #4** VALUES +– 1 STD
FOR CONSTITUENT= NFR AT EASTERN CROSSING



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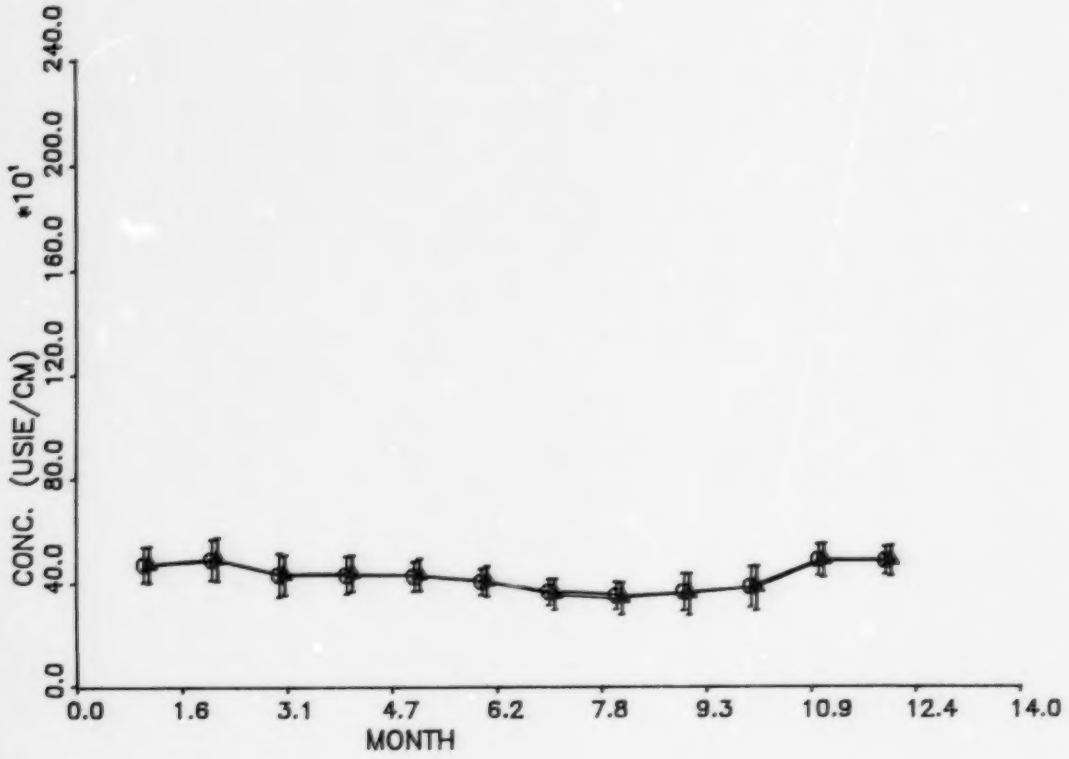
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= CONDUCTIVITY AT MILK RIVER TOWN



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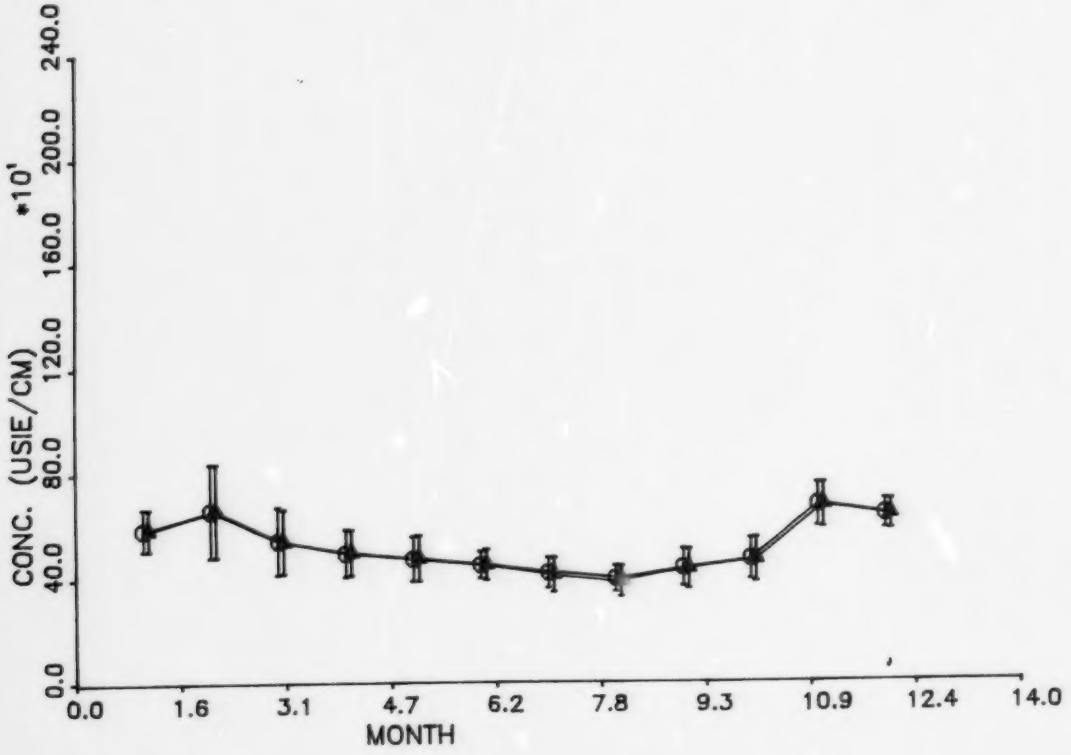
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS **#1 & #4** VALUES +– 1 STD
FOR CONSTITUENT= CONDUCTIVITY AT EASTERN CROSSING



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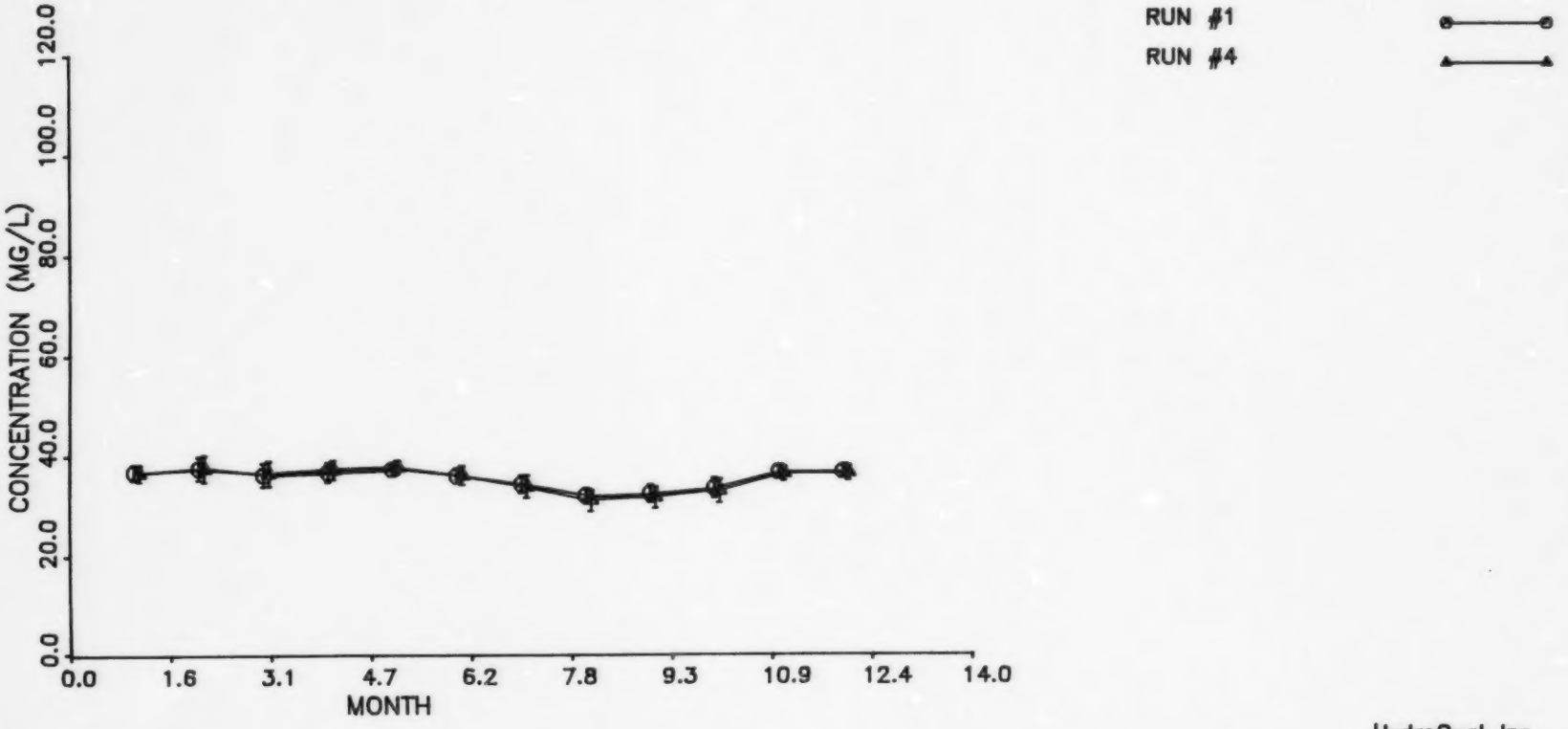
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= CALCIUM AT MILK RIVER TOWN



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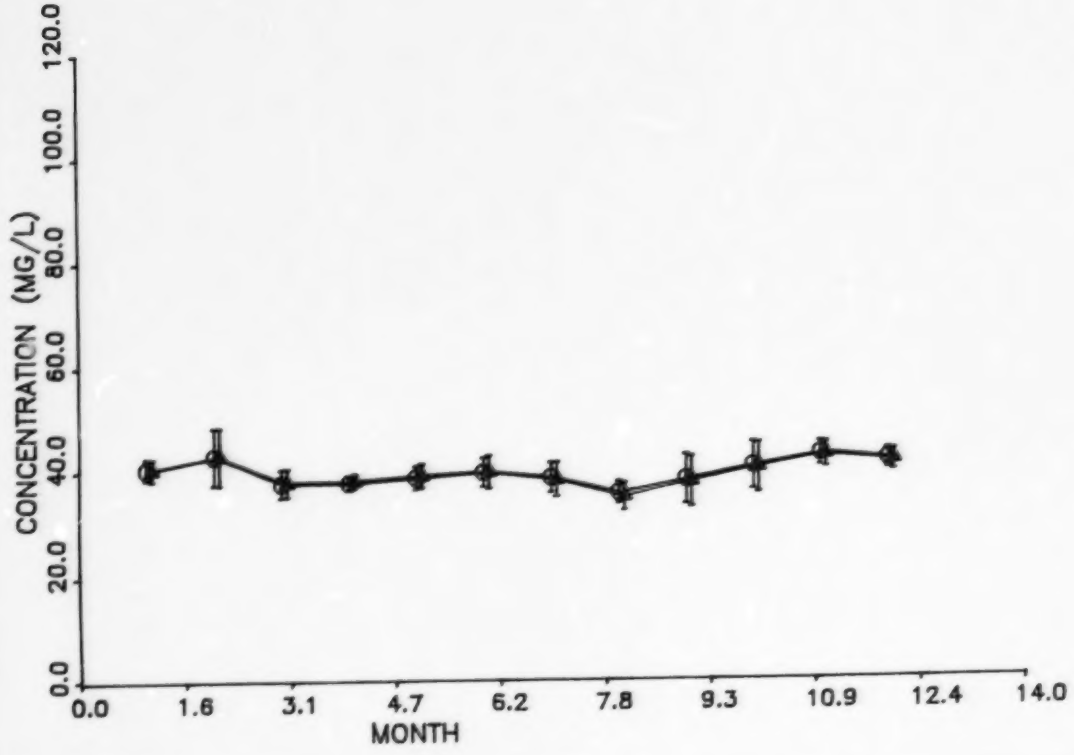
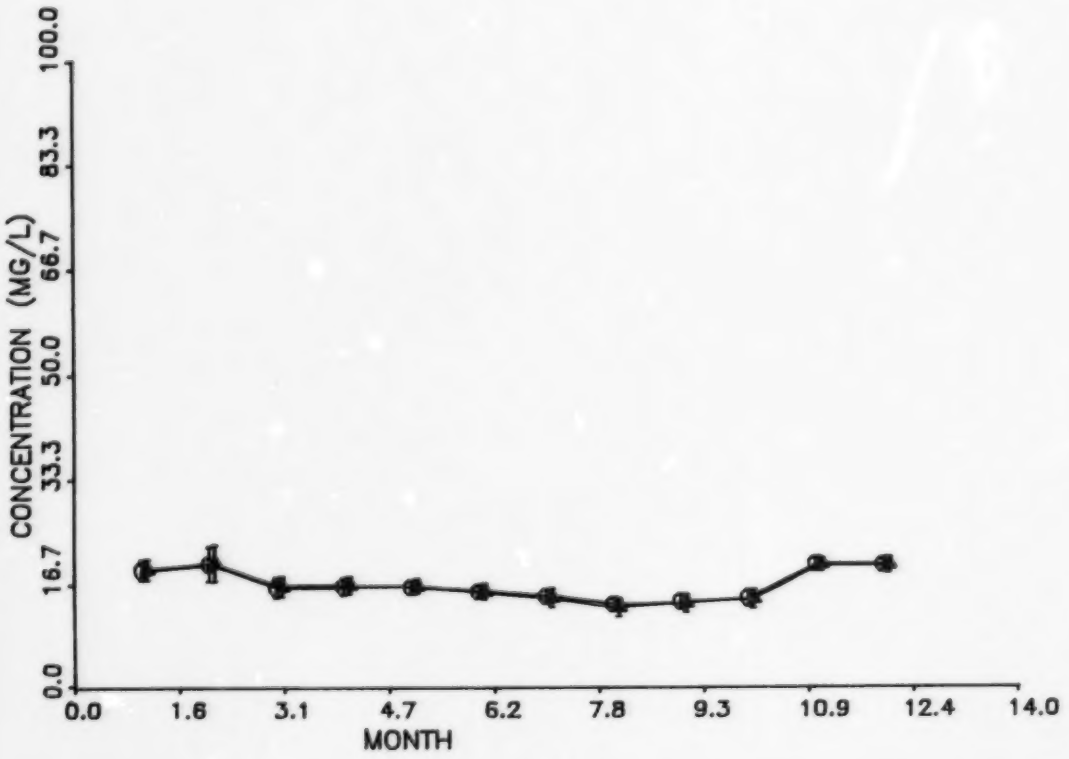
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS **#1 & #4** VALUES +– 1 STD
FOR CONSTITUENT= CALCIUM AT EASTERN CROSSING



HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= MAGNESIUM AT MILK RIVER TOWN



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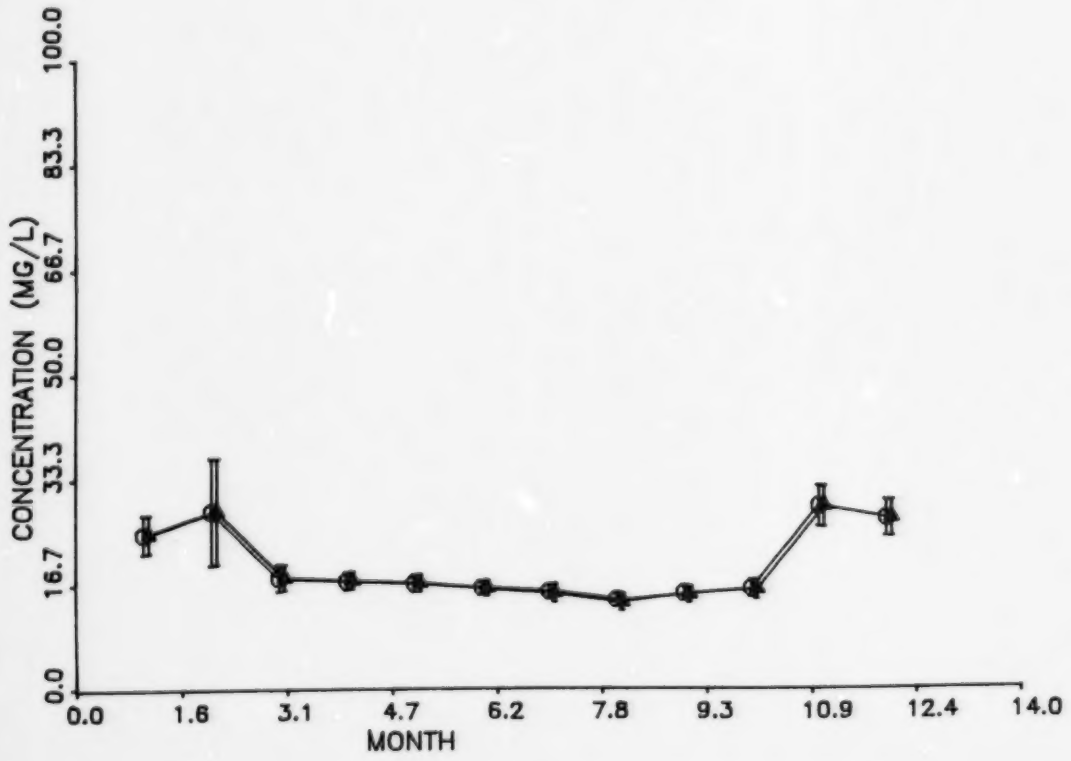
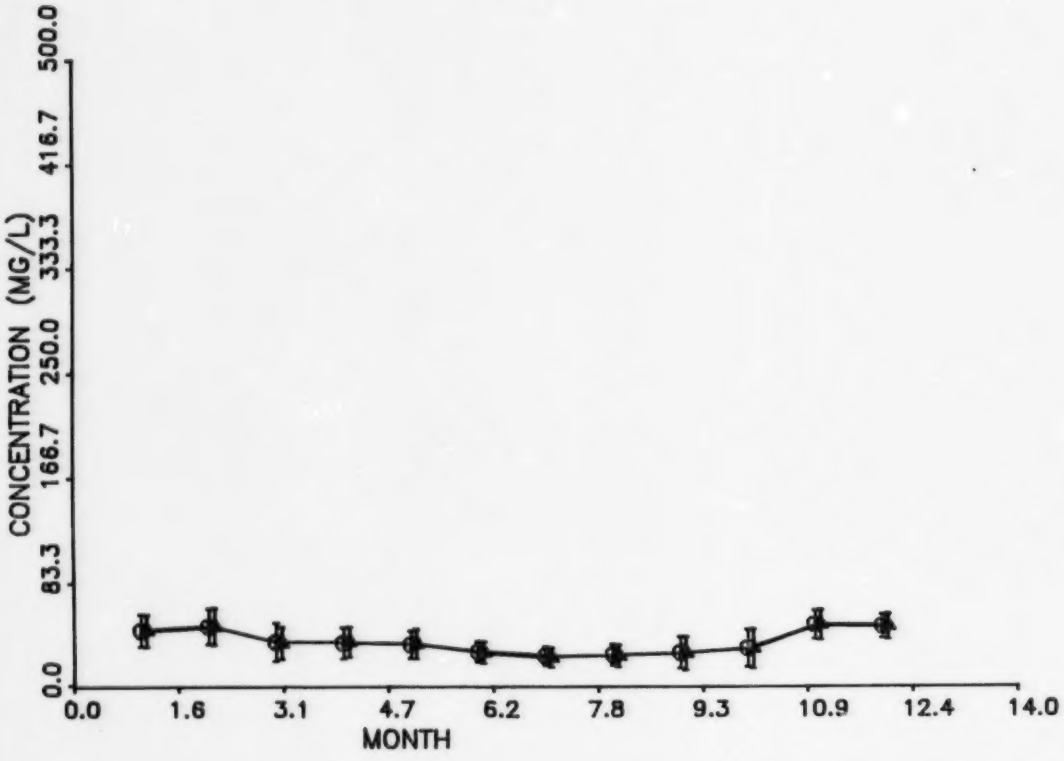
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS **#1 & #4** VALUES +– 1 STD
FOR CONSTITUENT= MAGNESIUM AT EASTERN CROSSING



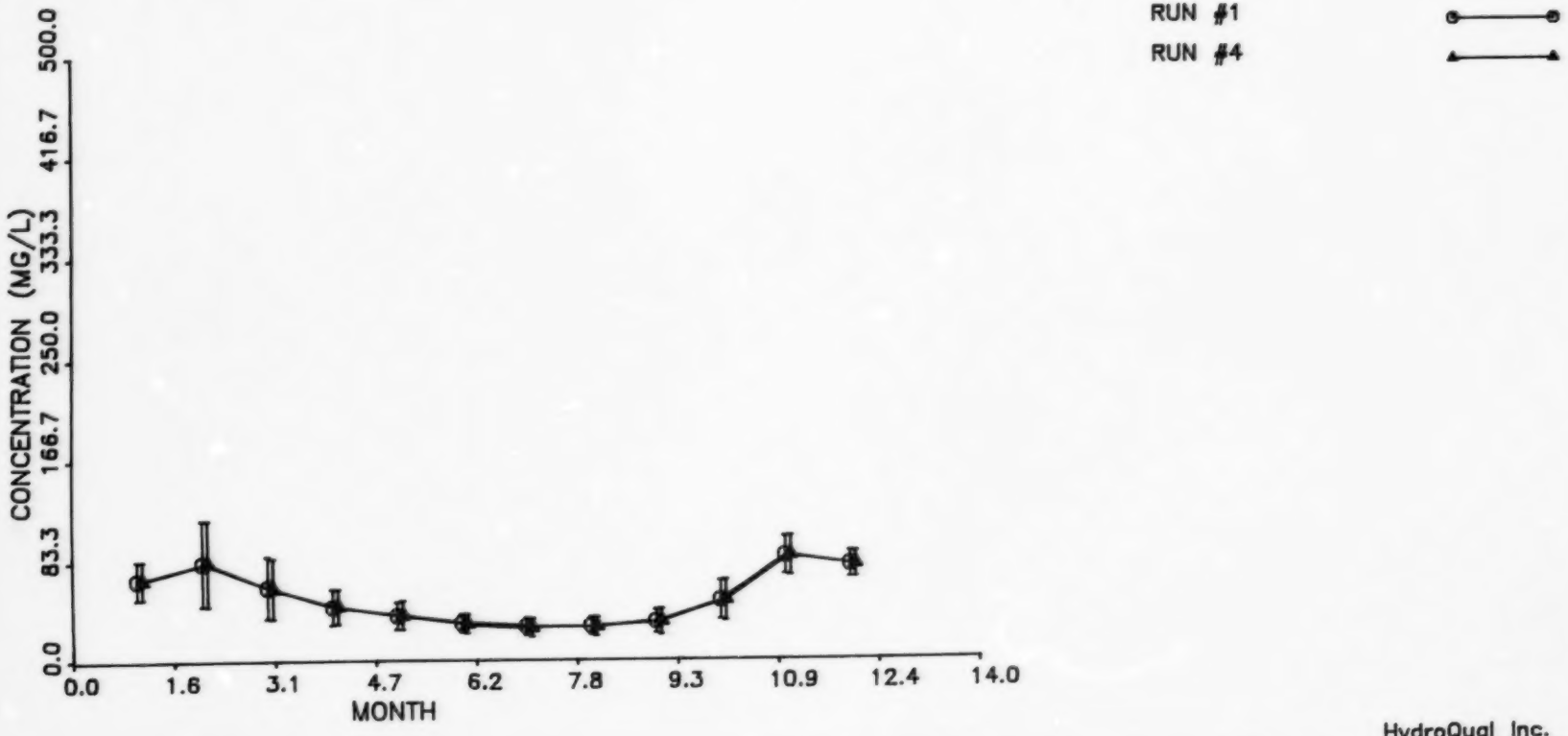
HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= NA AT MILK RIVER TOWN



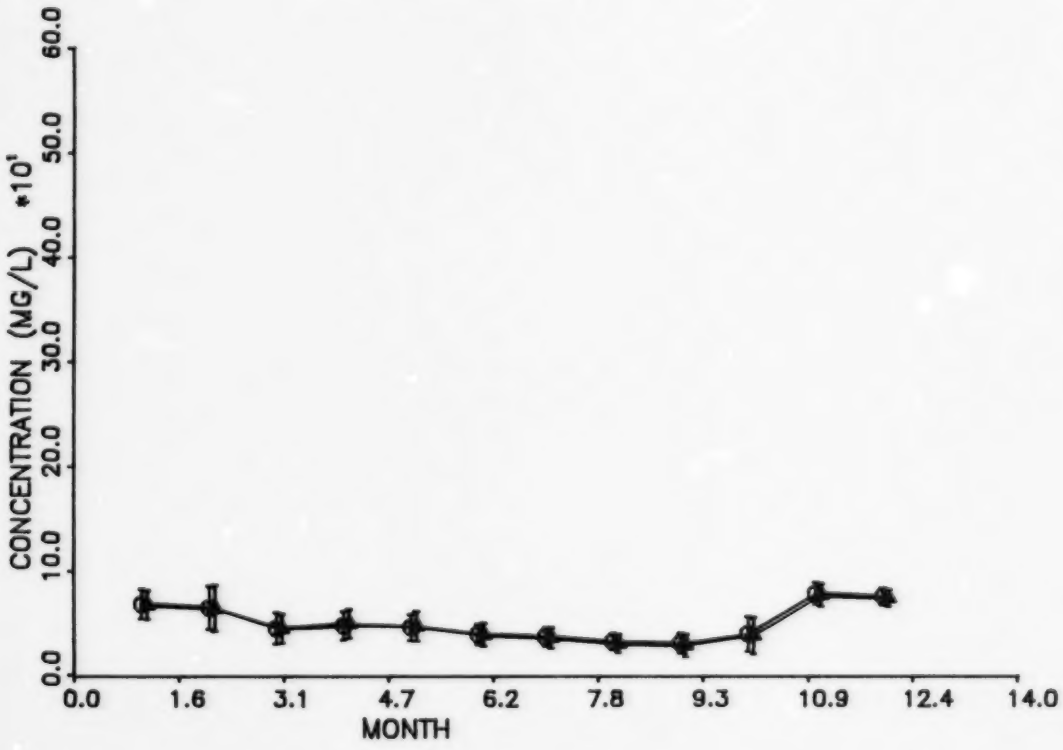
HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS **#1 & #4** VALUES +– 1 STD
FOR CONSTITUENT= NA AT EASTERN CROSSING



HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= SO4 AT MILK RIVER TOWN



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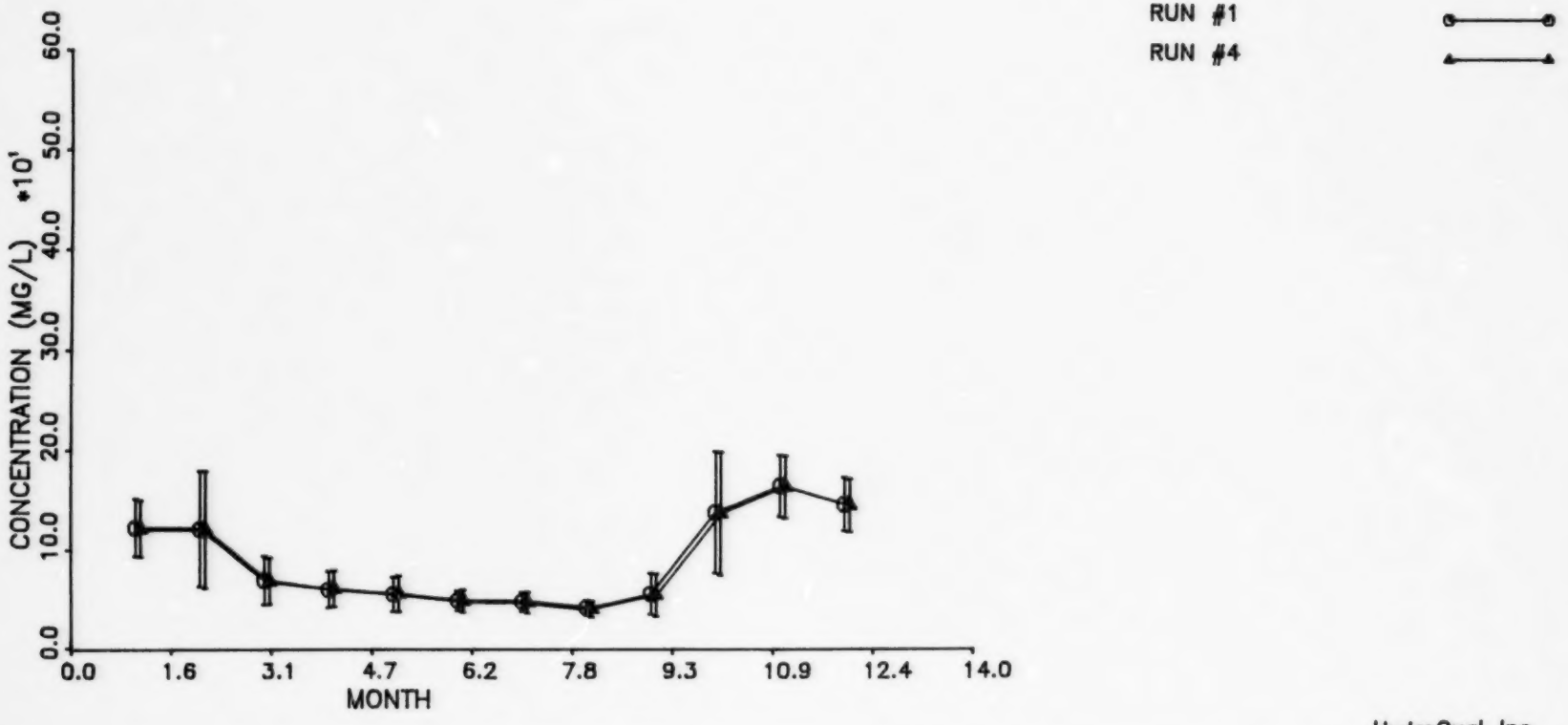
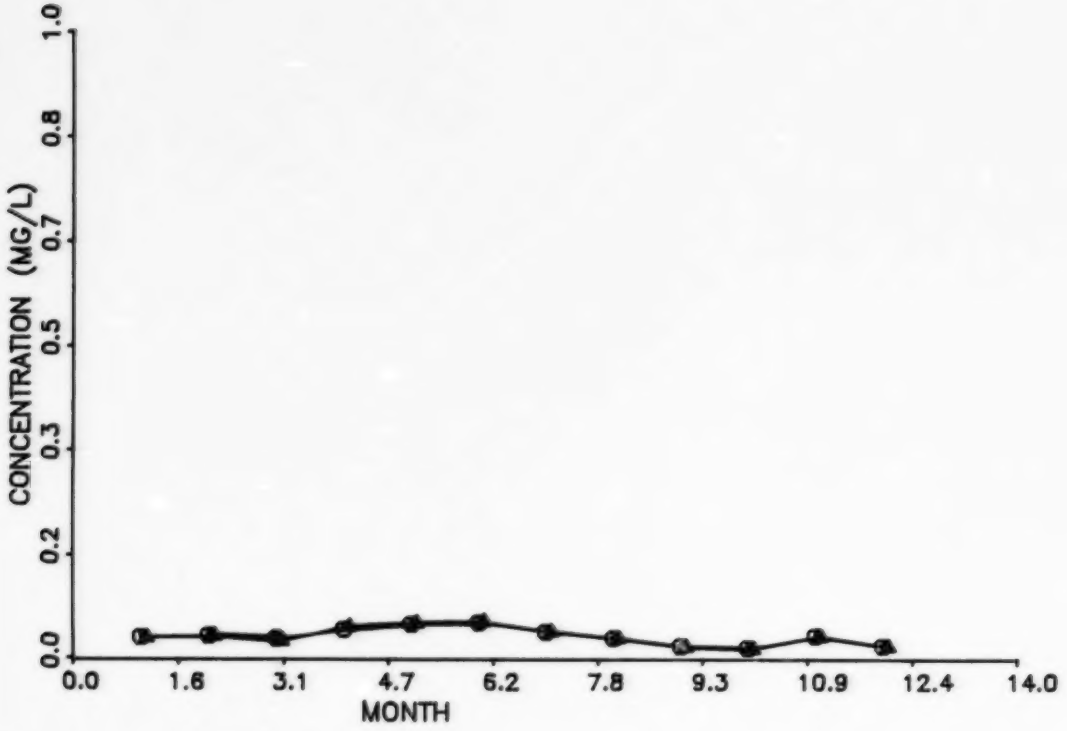
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS **#1 & #4** VALUES +– 1 STD
FOR CONSTITUENT= SO4 AT EASTERN CROSSING



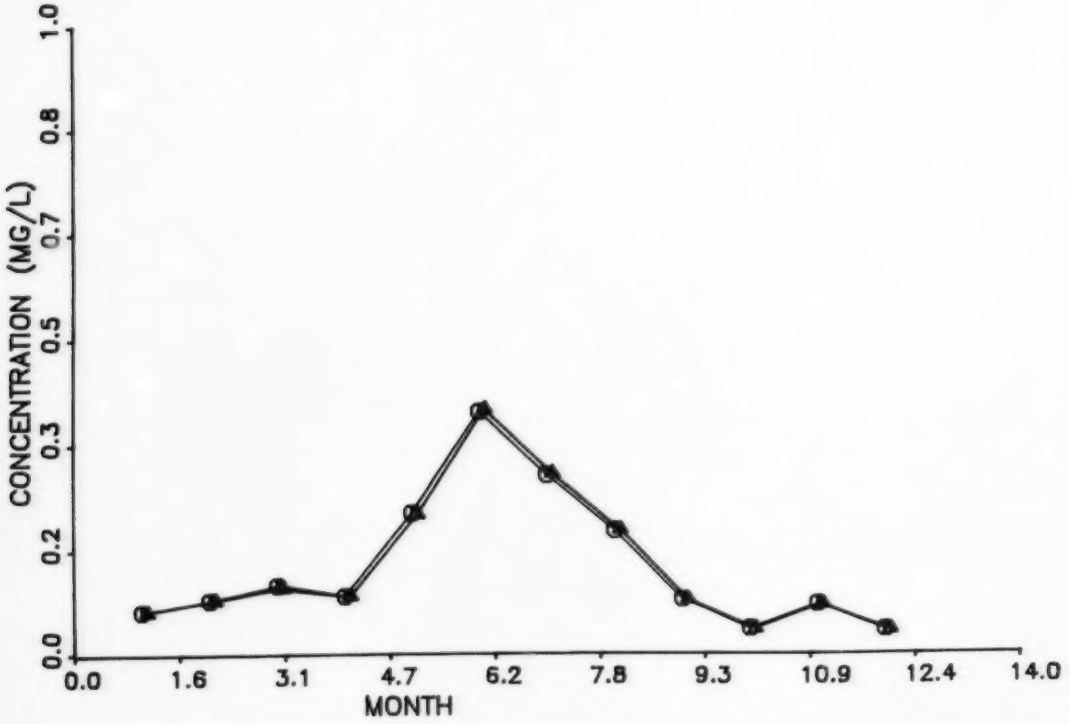
HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= TP AT MILK RIVER TOWN



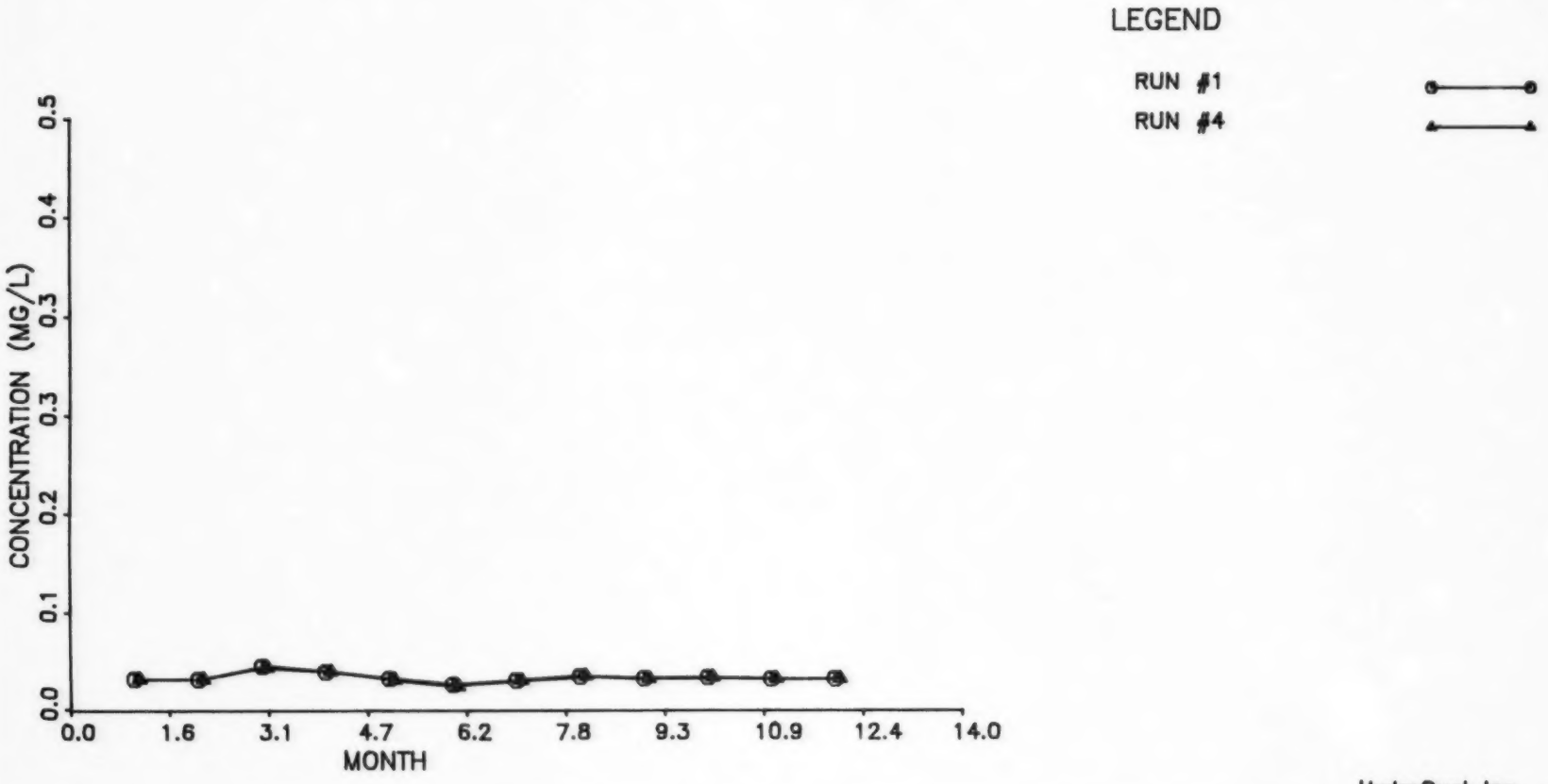
HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= TP AT EASTERN CROSSING

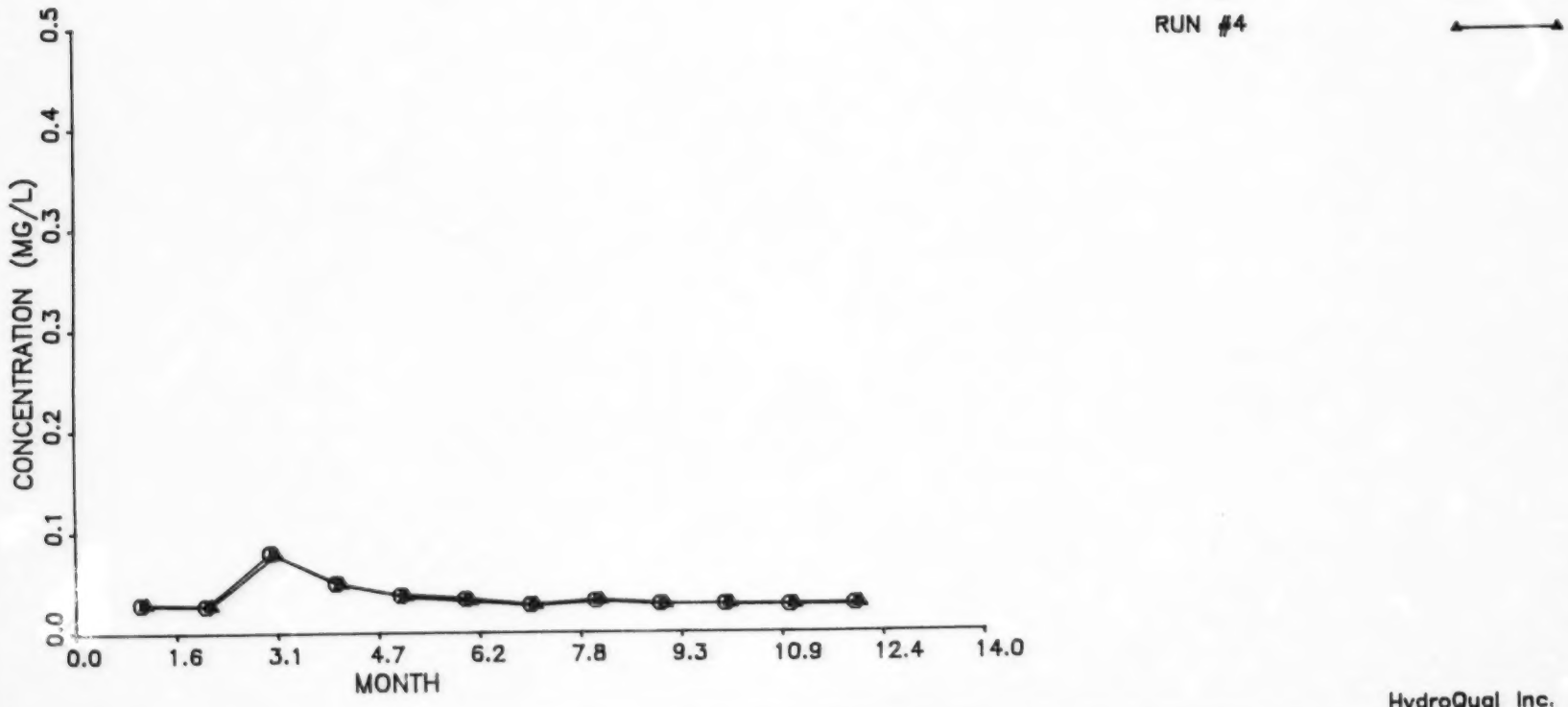


HydroQual Inc.

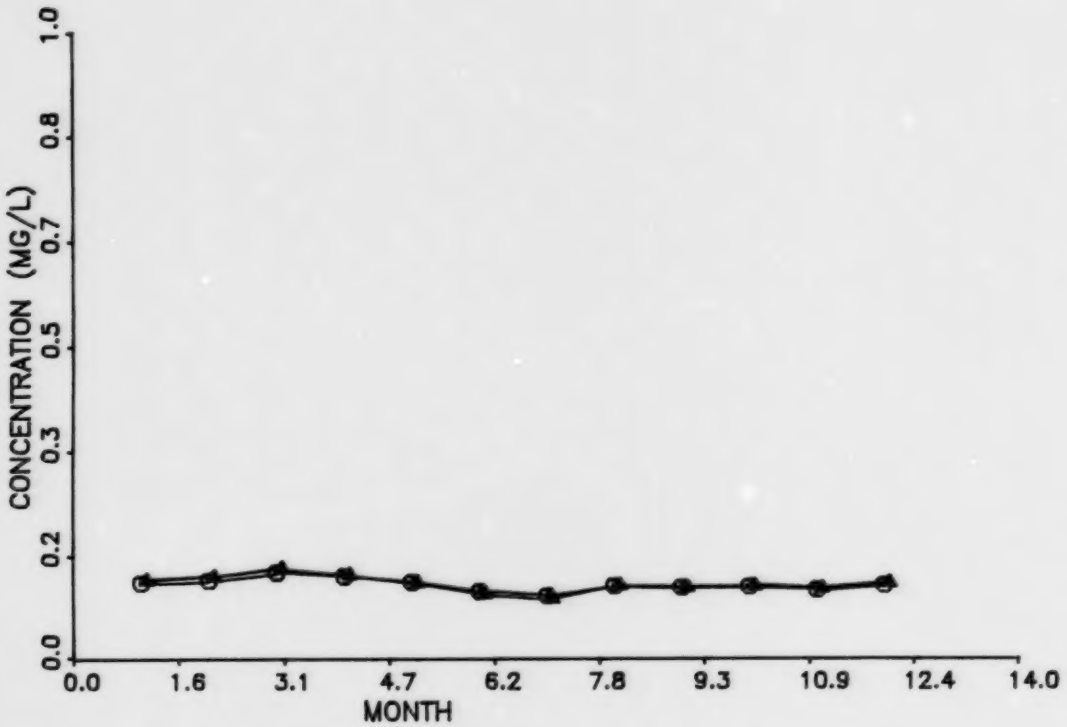
MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= NH3 AT MILK RIVER TOWN



MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= NH3 AT EASTERN CROSSING



MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= NO23 AT MILK RIVER TOWN



HydroQual Inc.

MILK RIVER – WQPM MODEL RUNS
RESERVOIR RUNS #1 & #4 VALUES +– 1 STD
FOR CONSTITUENT= NO23 AT EASTERN CROSSING